Vol. 66 No. 3

JOURNAL

of the

AMERICAN SOCIETY

of

NAVAL ENGINEERS Inc.

AUGUST, 1954

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Vol. 66 August, 1954 No. 3

Published Quarterly at Washington, D. C., by The American Society of Naval Engineers, Inc.

Entered as Second Class Matter at the Post Office at Washington, D. C., and at Nashville, Tenn. Acceptance for mailing at special rate of postage provided for in Section 1103. Act of October 3, 1917, authorized on July 3, 1918.

Subscription Rates for Non-Members

The subscription price of the JOURNAL, postpaid to points in the United States and possesions is $9.00. Single copies, $2.25. To other countries, $20.00. Single copies, $5.00. All subscriptions payable in advance.

Make checks, drafts and postal money orders payable to THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

Advertising rates will be furnished on application.

Addresses will be changed at any time, but only upon notification. Immediate notice should be given of any delay in the receipt of the JOURNAL.

Address all communications for the Society to

THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.
605 F Street, N. W.
Washington 4, D. C.

The American Society of Naval Engineers, Inc., has no official connection with the Navy Department.

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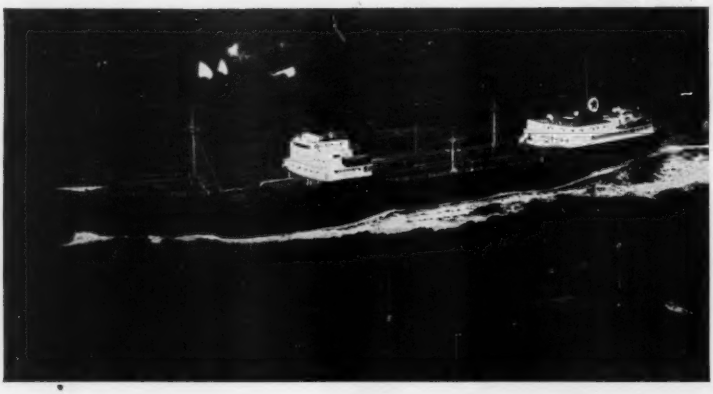

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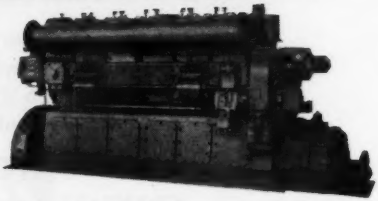

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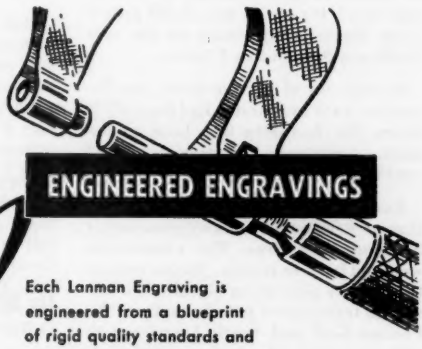

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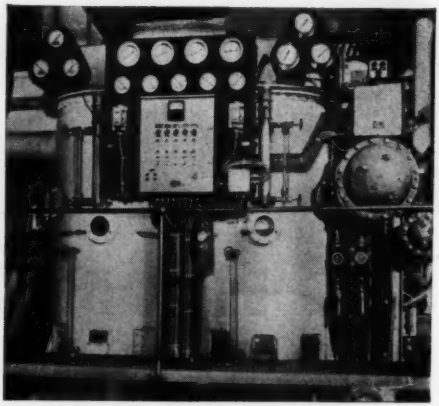

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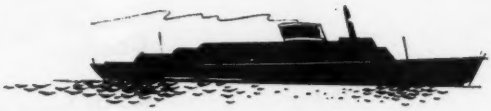

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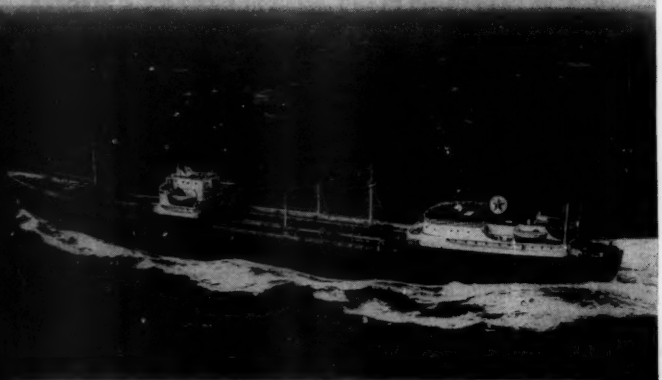

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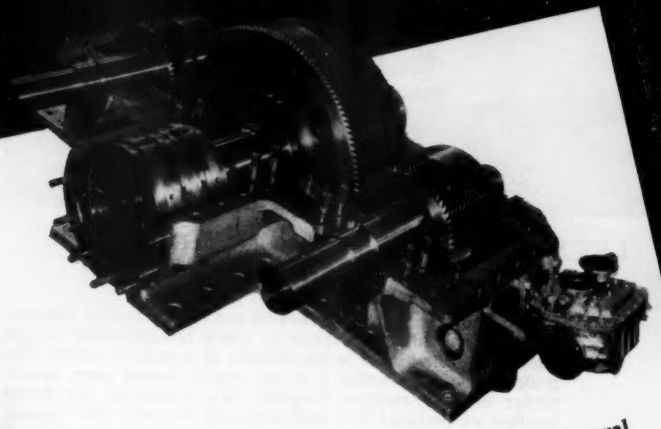

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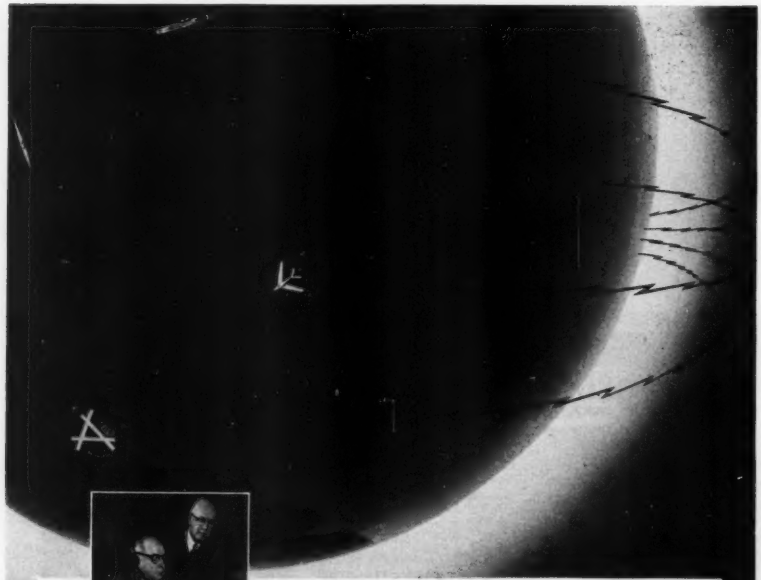

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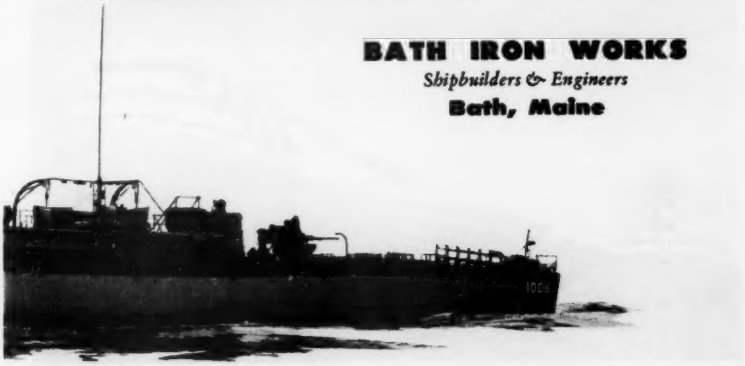

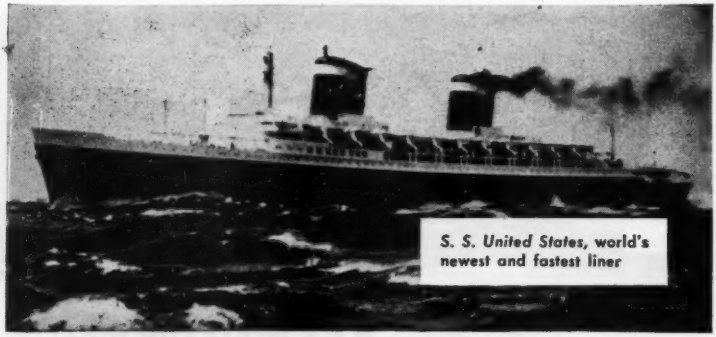

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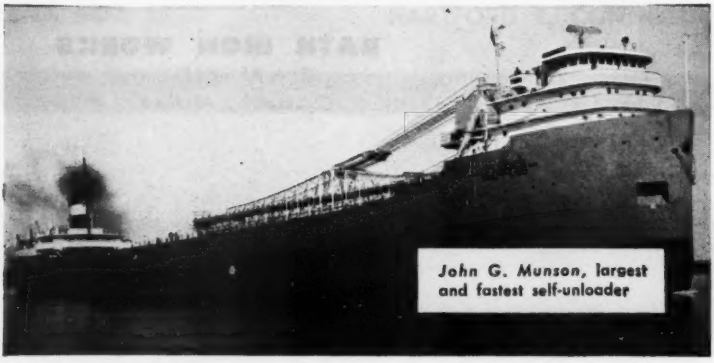

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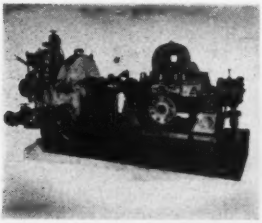
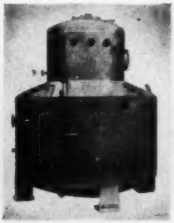
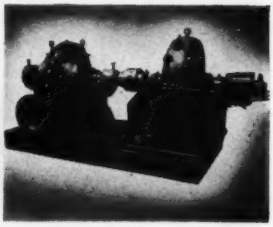

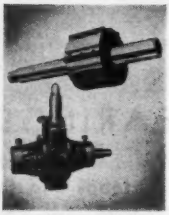
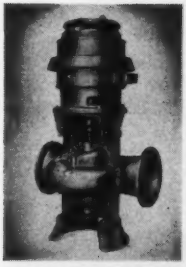
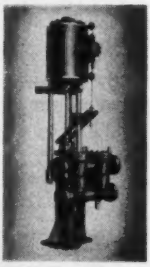
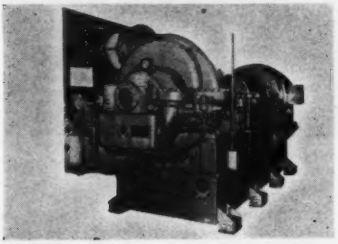
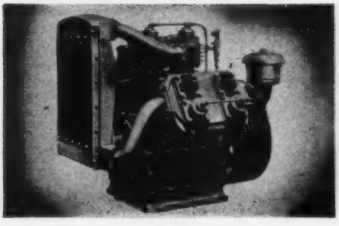

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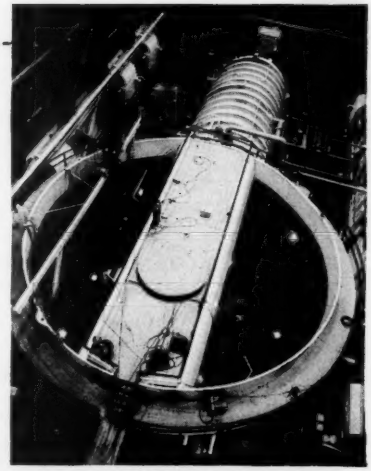

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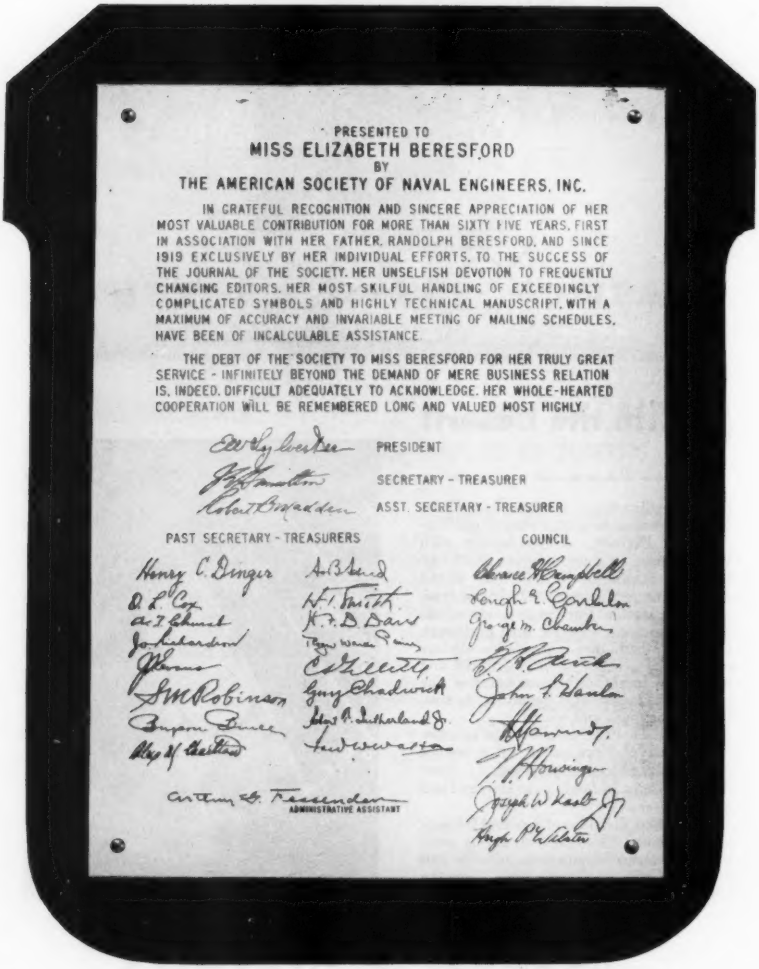

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Photograph of a plaque which has been presented to Miss Elizabeth Beresford by the Society.

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JOURNAL

OF

THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

VOL. 66. AUGUST 1954. No. 3

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SECRETARY'S NOTES

CORRECTION

In preparing the Secretary's Notes for the May issue of the Journal, the Editor jumped ahead of the Secretary to assure having everything correct. With prevision it was reported that a change had taken place in the Presidency and in the Council. The attempt to be *correct* caused six errors.

Admiral Sylvester discovered something about well laid plans. His expectation of departing from Washington on 17 May was altered by the vagaries of the service. Admiral Sylvester is still in Washington and therefore is still President of the Society. Admiral Furth is still the nominee of the Council to become President when and if Admiral Sylvester does depart. Similarly, Admiral Furth still remains a member of the Council and therefore Captain Heiser is still only the Council's nominee to replace him when he moves up when Admiral Sylvester leaves.

We regret that all of this happened and was poorly reported in the May JOURNAL. Had our ardor for the latest news been quenched for 48 hours we could have been correct and may not have missed the mailing deadline. The principals of the case have kindly accepted the Secretary's apology. The Editor has apologized to the Secretary. Both of them throw themselves on the tender mercies of the Members.

ANOTHER KIND OF CORRECTION

In order to mark a change of printers, the title on the backbone of the May JOURNAL was inverted. All further issues will revert to the original orientation. For those who save their JOURNALS and pile them or stand them on a shelf, this Vol. 66 will always be unique and distinctive.

STILL ANOTHER

We are beginning to learn how many *different* kinds of mistakes there can be. The May issue carries two photographs—one of the Nautilus on page 290 and the other of Mr. Newell on page 520. The former picture was furnished through the courtesy of the Electric Boat Division of General Dynamics Corp., but they were credited with Mr. Newell's picture. Mr. Newell's picture was available to us through the courtesy of Franklin Grant Studios, Portland, Maine, but they were given credit for the Nautilus. This we sincerely regret.

Mistakes

The above mentioned errors have been presented in a rather facetious way because, as it turns out, none of them has resulted or will result in any serious consequences. Perhaps these next two reported mistakes will not either but there is nothing facetious in the Secretary's heartfelt embarrassment on account of them. They are the type of thing which cannot be explained; they can only be acknowledged with regret.

On page 268 the original printer of the JOURNAL was stated to have been Robert Beresford. In fact, the R. stands for Randolph and the correct name of the father of our much respected Elizabeth Beresford was

Randolph Beresford

On page 520 the caption to the photograph and on page 521, the obituary of Mr. Newell gave his first name as David. As everyone who knows Pete is aware this is not correct. His name was

William Stark Newell

THE BRAND AWARD

The Brand Award, which was instituted by Mrs. Brand to commemorate her late husband, Rear Admiral Charles L. Brand, USN, was awarded on June 11, 1954, for the first time to

Lieutenant (j.g.) James Wilbur Carpenter, U.S. Navy

Lieutenant Carpenter, who is a member of the Society, stood highest in the graduating class in Course XIII-A, Naval Construction and Engineering at the Massachusetts Institute of Technology, in 1954. Lieutenant Carpenter, following his graduation from Tech, has been ordered to duty at the Norfolk Navy Shipyard, Portsmouth, Va.

THE LAMB AWARD

The Lamb Award is made to the Senior midshipman who will be commissioned in June at Rice Institute and who stands first in the Naval ROTC in mechanical engineering.

The 1954 award has been made to

Thomas Erling Lee

whose home is at 3520 Vincenna Place, New Orleans, La. He has been commissioned an ensign in the line, U.S. Navy.

CAPTAIN R. B. MADDEN

Captain Madden, who has been carrying a very heavy portion of the burdens of editorship of the JOURNAL has been transferred from Washington to the Naval Academy at Annapolis, Md.

We are happy to announce that, even though it will be more arduous for him, he has consented to continue to act as Assistant Secretary-Treasurer and the Council has accepted this offer with enthusiasm.

Before his departure from Washington, Captain Madden was the guest at a small luncheon tendered by those who served with him on the 1954 Society Banquet Committee plus a few from the Bureau of Ships. All present were there because their contacts with Captain Madden had convinced each of them that he was entitled to tribute.

FREON

On page 516 of the May issue we published a letter from the du-Pont Co. Too late for that issue, we received another letter which contained the following paragraph:

"As you propose to print our letter in the May issue of the Journal of the Society, we would greatly appreciate it if the fourth paragraph of our letter could be amended to incorporate this suggestion. It would read as follows:

"In addition, when another company or publication uses our marks, we ask them to designate the marks as those of the du Pont Company to avoid any doubts as to the ownership of the marks. Of course, it is sometimes difficult to combine the indication of ownership and the generic term with the mark in advertising copy, displays, etc. In such instances we often suggest that the indication of ownership and the generic term be combined in a footnote to which the attention is drawn by the use of an asterisk or other similar device immediately following the marks. In the case of the trademarks 'Freon,' 'Freon-11' and 'Freon-12' such a footnote might state, 'Registered du Pont trade-mark for fluorinated hydrocarbon refrigerants, or trichloromonofluoromethane, or dichlorodifluoromethane' as the case may be."

ON PRINCIPLES OF ADMINISTRATION AND GUIDANCE OF PERSONNEL WORKING IN MILITARY RESEARCH AND DEVELOPMENT

DR. A. BAEUMKER

THE AUTHOR

The author served twenty years as an officer in the German Army. After voluntary retirement in 1927 he was a counselor of the German Ministry for Transport and Communications working particularly, for aeronautical research and development. Beginning with 1933 as Director of the Air Research Department, Air Ministry, he organized and supervised the several research institutions which composed the overall aeronautical research system of this country. For nine years he was Acting President of the Lilienthal Society for Air Research and Chancellor of the German Academy of the Aeronautical Sciences. He retired from the Directorship of the Research Department in 1941. Since 1946 he is working for the US Air Force in different assignments.

The material presented in this study does not represent in any way ideas or policies of the Military Services, but represents considerations of the author based upon experiences accrued in his professional life with aeronautics of 40 years.

INTRODUCTION

1. During the life of the present older generation the first two world wars have occurred. These two wars basically changed the world political, economic, cultural, and social structure and, of course, the means for warfare themselves. The present state of the world is characterized by political imbalance.

At the beginning of this century, only fifty years ago, the then powerful navies represented a stock of armories of remarkable military-technical variety. On the other hand, at this time, weapons and military equipment of the armies of the foremost powers were large in numbers but confined to a very limited number of types. In the two world wars which occurred in these fifty years basic changes took place in war technology and, consequently, in the military art of warfare.

First of all, air warfare as a new military means changed the very foun-

dations of naval and ground warfare. More than that, air warfare as such has become an element of independent, self-sufficient actions called strategic-air warfare. Our generation saw only the beginning of this revolution of warfare through new techniques. This development will grow in extension and in impetus, at an immense scale. No end presently is recognizable in these gloomy ways of mankind.

New means are looming in the background: atomic and thermonuclear weapons, etc., which change the overall distribution of power on earth. Combined with air warfare they open new ways for inter-continental policies, for military strategy, and also for peacetime economy.

Unmanned airplanes, called guided missiles, enter the picture of the developments of peacetime transportation and of new military means.

From all these developments has resulted a new buildup of world power blocs. The progress of world technology is the prime-mover in this revolution, but not of the will of the soldier.

The soldier adapts the art of warfare to the inventions and to new technical creations discovered by natural sciences and applied to technology. He establishes "military requirements" but these, mostly, are only the consequence of actions in the purely intellectual fields of science and engineering. In other words, the revolution or evolution of human general knowledge, subsequently, is focused by the soldier into the military art.

On the other hand, the expectations for military applications of new inventions and technical creations greatly influence the overall intellectual trends, the ways and means, and the quantitative extension of the efforts made by natural sciences and technology. All in all, it is a seesaw process of give-and-take.

In purely intellectual fields science and technology have the lead; in the practical technical and military application of the main parts of the intellectual working results, the soldier is the leader.

2. The combination of all these tasks of "national defense" into one working system of intellectual, material, economic and military "economy" is an extremely complex endeavor. All military powers on earth are wrestling with it.

The basic foundations of life of the individual nations concerned with these tasks are highly different. Hence, the solutions selected by them to solve these problems in order to establish a well working system are also greatly divergent. It is difficult to define, even to recognize from outside, the basic presuppositions of good solutions for any of these nations according to the basic presuppositions of their individual lives.

Nevertheless, fortunately, some fundamental elements for organizing efficiently the defense preparations in military research and in its application to technology are common to the systems of life of all nations. By defining, or at least by recognizing, such common basic elements we are able to generally support the establishing of sound methods of leadership in these matters. Sometimes, even, we may be able to recommend some "basic formulas" for the approach to, and the solution of these tasks.

3. The revolution of warfare by military research and development is indicated by the rapidly expanding working programs, expenditures, fa-

cilities and personnel for military purposes of this type. At the outbreak of World War II the overall efforts were small, even those of world powers like the USA and Great Britain. During that war, for the first time in military history, the immense importance of these activities for the outcome of the military operations was shown on a large scale. The few nations which intellectually took the lead in these fields developed very extended and complex working systems of great efficiency: on the top of them the USA, Great Britain and, of course, Germany.

The unsatisfactory political results of this war, and, particularly, the succeeding Russian political expansion in post-war times, instigated the Western nations to re-establish and to expand their military research and development activities and the establishments serving them.

Presently, in 1954, more than one-third of the overall national expenses of the USA in research and development are devoted to military tasks, directly. 1.3 billion dollars have been, or will be spent for these purposes this year, industry having the greatest share in the overall efforts. This enlargement of expenses alone, from a level of a few million dollars spent in 1939 for military purposes of this kind to far more than a billion in only 15 years, shows far better than anything else the immense implications resulting from the problem of managing this realm.

The repercussions of this vast expansion are felt within the whole national economy, in culture and education and, particularly, in wide fields of world policies.

Improving the working methods of this military research and development, therefore, is a problem of the welfare of the whole nation. Discussions on basic problems of this field have far reaching significance.

4. There was war in the first five to six years of this vast expansion of the military work in research and development. For reasons of the national security public control of all these military efforts was then extremely limited. The uneasy political situation after the last war greatly limited, for the same reasons, participation of public interest in these affairs. This situation will not change quickly; it even may be aggravated by new world political tensions.

The basic elements of organizing the work of *science* have been developed in centuries by the Western orbit, under full participation of public interests. —*Industry* best has grown up under an economic system of "free enterprise" which also entails widest publicity on one side and the corrective means of "supply and demand" on the other. —The seclusion of *military* research and development from the benevolent but persuasive influence of public criticism involves great dangers for a true "economy" of all these efforts. For security reasons it is impossible to basically change this situation, but at least some corrective means are available which may prevent deteriorating trends of operation and a waste of public expenditures for these tasks. Checks on the effectiveness of all these efforts are required: for the work of the Government, for military science, and for industrial war development work in particular. Industry has the greatest share of public expenditures for these purposes; hence, its responsibility for enhancing general progress in defense matters is also the greatest within all the groups concerned. There is some political fight to diminish, even to avoid this control.

Control *of* the Government—in our case the Defense Establishment—*by* the Government, viz. the Legislature and the Top-Executive (particularly in the way of appropriating money), is very tight. Compared with this, the control of industry in regard to the effectiveness of work done by it for military research and development is exercised on a much smaller scale. In the way of its broad political influence industry is better prepared to represent its case. Government agencies involved in these matters not rarely are pressed into the unhappy role of a defender. It will be a wise measure on the side of the top leaders of the nation to establish—or, if necessary, to *re*-establish—a balanced system in the distribution of responsibilities between these two, even three, main groups:

(1) Government agencies, (2) industry, even (3) institutions of science. In some ways responsible Government agencies need protection against unjustified criticism. On the other hand, sound criticism is the first presupposition for obtaining optimum effectiveness. It was a very fine procedure to introduce into the British constitutional system an organized opposition, called His (or Her) Majesty's Loyal Opposition.

The "organization" of a sound criticism within the military research and development system always should be a primary concern of its leaders. By nature, public control always will be too small to obtain these ends. Therefore, self-control is required.

5. The prime mover of progress in overall research and development is the human brain; this also applies to the military tasks. Brainpower is a precious treasure of any nation. Important men characterized by ingenuity, wisdom and other eminent capabilities are extremely rare. A nation depends on them. Their personal forces cannot be wasted through lack of support. Their creativeness must be stimulated in the interest of the nation. Environments must be created which enhance their working efficiency. To a certain degree, institutions for the support of their work must be adapted to their character, working methodology, even ambitions. This is the way the ingenious leaders of science and engineering were handled in the past by some governments of Europe—with excellent results.

Decisive for the measure of progress obtainable by research and development work, furthermore, is the average intellectual standard of the more important groups of workers; scientists and engineers and skilled labor. The higher the national average intellectual standard is, the greater will be the expectations for finding out and augmenting the numbers of top leaders in the intellectual realms.

6.a. Considering this classification of people important to general progress in research and development, we may say that two different main types of research and development institutions are required: (a) those which use the pre-eminent, outstanding, even singular capabilities of certain individuals and (b) those the work of which is based upon average national intellectual standards of working efficiency.

Institutions of the first type (a above) will be small in numbers of people employed, in facilities provided for work, in expenditures, and somewhat limited in the extension of their working programs which always will have distinct characteristics of individuality. In case such institutions are more extended, the organization of team work within them—because of the individualism of the top leadership

—will be an intricate problem not lightly to be solved.

Institutions of the second type (see b above) are typical for top organizations of government and industry doing work in broad fields of modern science and engineering. Often they are large in size but—on the side of the government—they are more lightly to handle than the first group. Particularly *military* research and development top leadership prefer to establish, or to support, this type of organizations (type b). This type reacts more quickly to the method of command decisions. Personalities play too great a role in the first type of organizations. —This situation entails some dangers for obtaining optimum results of work within the overall work for military research and development. The facts show the great importance of rightly selecting the military top leadership of this field.

b. To some degree the scientific institutions for the exchange of experience within the intellectually prominent personnel of this field—societies and the like—show a similar differentiation by their statutes, and by the membership of which they are composed: Top ranking experts of the individual fields of military research and development are combined for united action by special advisory groups, i.e., councils, etc. of a type similar to that of the classical "Academy of Science." Their work covers fields limited in the (quantitative) extension of their efforts; but their activities are concentrated upon *main* tasks of overall guidance. The second type of organizations for purposes of exchange of experience within ranking experts is the scientific and/or technical society of the type commonly known within all Western nations. Their working programs are widely extended; the numbers of members often are large. In general, the aims of work of the first type of organizations mainly are based upon the results of work inspired by the second type,—on a higher intellectual level.

c. For practical reasons this subdivision of intellectual responsibilities in the overall intellectual working process is unavoidable. It needs some carefully thought-out methodologies for the selection of the personnel concerned. This problem concerns one of the gravest tasks of general leadership in the realization of modern research and development work.

7. Up to the beginning of this century, the universities and similar institutions nearly exclusively were the promoters of progress in science, through improving the overall knowledge by teaching and by doing research work. Only fifty years ago the influence of the industry upon the cultural endeavors was relatively small, that of the military upon them was negligible. —In the meantime industry has taken away from the cultural institutions larger parts of their former overall national responsibilities in shaping the technological progress through scientific and technical research and development work. —Additionally, since World War II, the military impose their policies upon the cultural realm by contracting with the universities for war research and development. Moreover, on their own, they do large-scale research and development work in facilities the capabilities of which, in many cases, by far surpass those of the universities.

On the basis of these overall developments, defense agencies and the national economies of the leading world powers were forced to establish a system of intimate mutual cooperation for adapting the industrial process of producing goods to the needs for

mass production of weapons and military equipment. A kind of a "condominion" evolved by mutual cooperation between the two main groups, the military and the industry. The beginning of this type of organization dates back to the second half of World War I, particularly in England and Germany, and somewhat later in the United States.

This system was enlarged in World War II by introducing into it, with some kind of independence, the field of military research and development.

But during the last war the importance of military research and development as an independent, third, main factor of national defense was not understood to its full extent. In this war the new field rarely obtained the independence which would have been necessary to stimulate progress of weapons in the shortest possible time. Particularly exploratory research and development suffered under this situation, in the United States, in England and in Germany as well. Only the United States made one exemplary new approach to the overall problem of organizing military research and development on a large-scale basis, in a new main field: atomic energy. Smaller but also very successful steps of this kind were made by the USA and England in the field of electronics. German organization in both fields was a failure. The result of these American and British efforts was a breakthrough of new ideas, and their wonderful application within an extremely short time. In most of the other military technical fields the lack of some organizational independence resulted in an overconcentration upon the incremental development of conventional arms. Thus, the promotion of a new approach to the problems of warfare unnecessarily was lacking widely. As yet the importance of this fact has not been fully recognized by the victorious Western nations.

Progress of military research and development as an independent main branch of the war preparations in peacetime largely will depend upon the brainpower of scientists and engineers working in this field, and upon the skill of its workers and planners. Hence, the personnel policies for this research and development have a decisive significance to overall progress. We will discuss some of the most important principles on which, in the future, these policies should be based:

THE PROBLEM OF LEADERSHIP IN MILITARY RESEARCH & DEVELOPMENT

1. An Introductory Remark

In the following discussion we remain, in the main, on the purely abstract side of the problems involving personnel policies of military research and development. This is done intentionally, in order to facilitate individual investigations of a strictly objective type by persons interested in these problems—on the basis of their knowledge of the present situation. We do not want to criticize in any way the present state of affairs of any country which may make larger or large military research and development efforts. The main purpose of these discussions is, solely, to stimulate sound self-criticism and a constructive will for improvements within the limits possible, and the methods applicable at the time.

2. Basic Organization of Military Research and Development Activities

An investigation of the basic elements of military research and development must first of all define the individual intellectual and material

scope of the entire field. This is generally accomplished by subdivision into (a) basic (or fundamental) research, (b) applied research, (c) development, and (d) testing and evaluating, in short: testing.

From this we see that entirely different types of intellectual personnel operating very different types of equipment must participate in the field: (a) basic research is a main task of the universities, of special research institutes, and of some specialized groups of industrial enterprises; (b) applied research is accomplished by universities and special research institutes and partially by industry; (c) the development of military technical equipment is chiefly the responsibility of industry while (d) the testing of such equipment is partly a technical industrial and partly a miltary task; to a limited degree also science contribute to the testing process.

It follows from this that within the military research and development organization a basic triad must guide the qualitative methods of personnel selection: (i) scientists; (ii) industrial technicians, and (iii) military technicians. They must complement each other's work in mutual fertilization. We thus arrive to establishing our

FIRST BASIC PRINCIPLE: *None of these three categories of experts must dominate over another category.* This is the paramount principle in personnel policy of military research and development.

Discussion:

The concept of military research and development is relatively new. Somewhat hesitatingly, this research and development emerged as a new field of the military art in the first of the world wars. For the first time, the second world war showed the influence of this field on the outcome of a war. A new world war will show even more dramatically the decisive role of the intellectual war effort.

In addition to the task of (i) military planning, preparing, and guiding strategic and tactical fighting actions, and in addition to (ii) the creation of a large military mass production system for the equipment of the military forces with weapons and equipment, we are now faced with the factor of preparing, in peacetime for war, the intellectual and material basis of (iii) military research and development.

War research and military development occupy an intermediate position between the military strategic and tactical tasks of guiding troops and the production tasks of war industry—as an independent and immensely manifold activity. Hence, this research and development constitutes the natural mediator between the military aspect of leading the troops to glory or perdition upon the field of battle on one hand, and the industrial task of military production in the factories on the other hand.

Leadership of this three-sided task (see above i to iii) requires special command for each of the three fields. In addition, there is the immense task of creating an overall command for all three branches to coordinate and stimulate the activities of the three individual groups.

The law of the trinity of power is unalterable since the modes of thought and work differ fundamentally in (a) the military, (b) in research and development and (c) in production. They overlap only in their marginal areas.

The importance of military research and development for the outcome of a new war is widely recognized. The process of translating this fact into practical measures, on the other hand, is slow, for various reasons. Most important for the reluctance to accept military research and development as a new independent military main field of action is the resistance of the leadership of the two older fields to accept the new concept, viz. the military and the war production leaders.

Precisely when military research and development will achieve the required degree of internal and external autonomy cannot yet be predicted. The prerequisites for such a healthy development differ among the individual Western countries.

The latest possible time for a conversion of the overall system of military guidance to the new concept is the time immediately preceding *the outbreak of a war*. Later attempts at reorganization can no longer reach their full effect. Who can predict with some certainty such an event in times of large world tensions? —The earlier in peacetime such organization is accomplished, the greater will be the internal strength of leadership and the effect of the available intellectual resources in the field of technical war preparations.

During a new global war, the intellectual resources of even the largest countries will soon be exhausted for the following reasons: (a) The tactical possibilities for the application of new weapons will be greatly enlarged and hence the fighting troops will require increasing numbers of technically trained personnel; (b) Combat itself requires increasing numbers of troops of all kinds; Considerable manpower is thereby withdrawn from military research and development and war production; (c) Industrial mass production requires a constant flow of new technically trained personnel; (d) Casualties at the front and, by bombings, at home will reach unimaginable and irreplacable magnitudes.

The organization of modern war research and development is at present still in an intermediate state. From past traditions in most countries the influence of purely military leadership upon the inner working process of military research and development is very high; that of ranking experts of science and engineering is more based upon advice than upon immedate responsibility for actions. This situation will change in the coming period of an unavoidable evolution of the entire military working system to the needs of warfare by research and development as an independent means of war. These changes in some cases even may obtain "revolutionary" characteristics, viz. in those cases in which fundamental changes of our basic knowledge occur through the progress of natural sciences and its application to modern war technology. Necessities always shape the course of actions in their own image, sometimes slowly, and many times under the pressure of internal crises.

In concluding we may say that it is a highly complex task to establish an intellectually prolific, militarily as well as economically satisfactory composition of the leadership of military research and development. Such an extremely complex task requires thoughtful and careful preparations. It needs time and good will on all sides.

3. *The Distribution of Responsibility for Progressive Work Among the Leaders of Military Research and Development Work*

In accordance with what has previously been said, the responsibility of leadership in military research and development must be divided among different types of leaders:

The scientific institutes are to be lead by scientists. Applied research should be lead by scientists with practical industrial and/or military experience and partly by men with purely industrial or military scientific backgrounds. New technological "development" is the typical field for industrial engineers. Testing requires, in addition to industrial engineers, personnel with a military frame of reference, especially soldiers with technical and/or scientific education.

But these are only principles. They merely provide a purely external description of general policy trends. It would be a great mistake to adhere too rigidly to this pattern. Wherever an outstanding or talented person of great scientific, technical or military understanding is to be found, he should be assigned to a position where the country as a whole will most benefit by his talents, particularly in regard to defense.

This objective can only be reached if this strata of leadership is chosen according to those methods of personnel selection which have proven the most valuable throughout long periods of time: In science those of the universities, in some applied research and in technical development selective methods of industry, in the field of military testing and in overall military guidance selective methods of the type used for General Staffs but adapted to the particular needs of the new world of military technology.

As we already have seen, military research and development is a new (third) group of military main tasks in preparing warfare within the overall field of modern military guidance. (Purely) military personnel policies of the past have been developed on the outlines of military command requirements. Industry, on the other hand,—the mass producer of military means—has its own free laws of personnel administration and guidance. As a substitute for new and efficient rules of personnel administration so urgently required for the new field of miltary research and development, a combination of administrative principles has been imposed upon this field derived from: (1) the traditional military rules of personnel administration—for the military part of the personnel concerned—and (2) the rules of the Government Civil Service Organization—for large parts of the civilians employed in these tasks. The rules of the latter group, Civil Service, were developed in times in which technology scarcely had won importance to the direct functions of government. In many Western countries large efforts have been made to at least adapt the *Civil Service* system to the new requirements — but with very limited success. Similar efforts made in regard to adapting the system of *military personnel* administration to these new tasks were even less successful.

In many countries military research and development is suffering under this state of affairs. It is particularly difficult to overcome the vast conservative forces of Government which in their thinking are based on the past. This is one of the gravest obstacles in obtaining an efficient structure of the personnel leadership of the new field. But it is unavoidable to overcome the obstacles and to go ahead on this way.

Military research and development leadership urgently needs the spirit of pioneers. This spirit and enthusiasm of work is the main element of prog-

ress at all. In many ways the too rigid application of the principles of military command on one hand and the strict rules imposed upon any Civil Service organization on the other are the opposite side to the daring spirit of inventors, heretics and even only individualists. The overall status of military research and development requires—as an important main element of quick progress — some kind of fluidity. The principles for military and Civil Service personnel administration, by nature, in many ways as yet are not elastic enough to fulfill the requirements.

If the present system by which a major portion of a nation's intellectuals become servants of the government, is continued, we face increasing rigidity and eventual petrification in this branch of defense which, so far, has been the most flexible. Turnover of some important parts of the personnel in creative positions is an important prerequisite for maintaining and accelerating the process of mental creativity.

The country which may find the best solution to this problem in the course of its preparation for technical warfare will undoubtedly also produce the best weapons.

THE POLICY OF SELECTING PERSONNEL FOR MILITARY RESEARCH AND DEVELOPMENT

(Criteria of Personnel Selection)

1. Performance as a Criterion

With the remarks made above we have already indicated one of the most important principles to be imposed upon the selection and guidance of personnel for military research and development, our

SECOND BASIC PRINCIPLE which says that *work performance should be a main criterion of job placement, salary, and distinct privileges derived from successful work.*

Discussion:

a. It is a very simple thing to establish such a fundamental requirement; but it is extremely difficult to apply it to a conglomeration of experts so divided in their ways of life by tradition, by administrative rules and by the expectations they have in regard to their future professional life. Some similarities may exist between scientists from universities and the experts coming from industrial life. Common interests are even so involved between the groups of officers and soldiers on the one hand and the experts having a Civil Service status on the other. But, in general, it will be a Herculean task to find out a workable system which insures the application of this powerful and most important principle into practice.

b. A great many people have a natural inclination toward comfort. This is generally associated with a striving for physical and economical security. Bureaucracy in governmental systems and in the administration and guidance of the armed forces provides a great measure of such economic security for its members. The tendency toward easy-going comfort is therefore difficult to suppress among government supported or employed personnel in many instances. But comfort is the enemy of every kind of true competition and, above all, the enemy of ingenious invention.

It is but an expression of the psychological undercurrents of our age that a great many of the mentally alert and creative persons employed in research and development are very anxious to achieve the economically secure status of the Government employee by being willing to accept lower salaries in return for job security. And they do not want to assume the risk they have under the rules of free enterprise of a salary reduction or dismissal as a result of a period of inadequate work performance. This applies to civilian as well as miltary personnel.

In our opinion, in pure scientific and technical fields only a carefully selected group of (civilian) scientific and technical experts of long-proven ability should be granted the kind of economic security in military research and development which compares to the economic security of a "civil servant." The award of such "tenure" might follow procedures customary at universities of the Western orbit. This personnel group then would have the task of assuring stability of the overall project over long periods of time; and it would have the function of continuously coordinating past experience with future projects.

For the groups of employees of a non-permanent status salaries and other kinds of incentives should be provided which are far above the standards presently usual in government "administration." This is necessary in order to attract high-caliber people for a limited time who otherwise would prefer to stay aloof from any kind of a non-permanent engagement with the government.

Soldiers and officers of outstanding capability should also have an opportunity for orderly participation, by other means, in such a system of incentive.

c. The creative capabilities of the individual scientific and technical personnel in research and development largely are in a fluid state: They mostly are either increasing or decreasing. A pure state of "stability" of the creative forces is a rare phenomenon since the state of the art in military research and development continuously is expanding and rapidly proceeding. Technical creativeness is the main element of progress at all—not technical planning. To stimulate the element of creativeness through appropriate selective methods, for all kinds of personnel in research and development always will be a main element of the overall guidance of this field. The performance principle must be the basis for these selective methods.

In case we would apply this principle too rigidly and, too radically, for the definition of job assignments, a great instability would result in the composition of the research and development personnel as a whole. This critically would diminish the overall results of the work done in this field. Therefore, we need a system of personnel selection by which the performance principle is *moderately* applied so that it does not destroy the internal, logical, consistency of the working process.

The leaders who are responsible for overall personnel policies must be highly experienced in the work of science and/or engineering. Simultaneously, they must be wise characters. Moreover, at their disposition they must have an excellent knowledge on working results obtained by the medium and upper layers of individual experts. It is entirely insufficient for an effective personnel guidance to think of the use of punch card systems for the selection of individuals to job assignments in military research and development. Nearly all the systems applied for the mass selection of per-

sonnel for industrial and military purposes are doomed to failure in the more or less "spiritual" realms of personnel selection for research and development.

Presently, in most of the great powers, the numbers of leaders may be small who in this field, fulfill the requirements of intellectual personnel guidance. This field, military research and development, is very new. It may be expected that the situation may improve in the future in case our first and second principle can be applied in a broader sense.

d. It is a logical result of the performance principle that neither academic degrees nor military ranks can be used as a means for selecting personnel to job assignments. It is only a result of historical developments that presently these degrees and ranks play such a great role in the system of personnel selection for military research and development. Neither the allotting of military ranks nor the obtaining of academic degrees is bound to the characteristic requirements for being a leader in science and engineering of this particular type. Their present use as a means for selecting leaders is a great impediment to progress.

e. No "yardsticks" can be applied in the realm of research and development in order to define the work performance of the individual, particularly the performance of the leaders. Publications, special reports, and books of basic importance to progress written by the more prominent experts of this field provide the most effective means for a kind of an *intellectual* "evaluation" of their capabilities. Speeches of importance to the overall progress of science and engineering made at professional gatherings complete the picture the individual expert creates in the professional minds on his capabilities and work performances.

The importance of these means for the personnel guidance is widely underrated; in military circles of some countries perhaps it even may not be fully understood. As a consequence of the deficient use of intellectual means for personnel guidance, purely administrative, i.e., *un*spiritual means are widely over-estimated. They are the gravest impediment to an intellectual evaluation of work performances. In their result they are opposed to introducing an "economy" within the spiritual realm of work in research and development. In these intellectual realms not "control" or "supervision" is required but energetic *help* for the appearing new energies of creative personalities.

f. The application of the principle of work performance to the fields of intellectual personnel guidance in military research and development is not only opposed by the usual human mental conservativism. More than that, it is directly opposed by professional egotism of different groups of personnel working for, or related to, this new field of activities.

2. *Qualitative and Formal Methods of Personnel Selection*

a. *The Military forces* select their men according to physical strength as well as according to temperament and education. Civilian vocational experience affects the assignment of only a limited portion of soldiers under such a system. The evaluation of combat fitness is generally a main criterion on this system of selection.

The officers in the fighting forces might, or rather should, have the highest type of military qualifications of the mentioned sort.

The quality of officers and men is systematically improved by military and physical training. The entire personnel system of the armed forces is built on the principle of self-sufficiency; i.e., it needs the aid of outside agencies only in exceptional cases.

The system of selecting officers and men is in itself extremely stable. The great changes of modern life and the expansion of technology into the realm of warfare have thus far had little effect on the system of selection of military personnel. The traditional recruitment methods of the nineteenth century were only more or less externally changed in most countries by the growth of twentieth century war technology.

Personnel lists and card files are the principal means for cataloguing and subdividing personnel in groups, to distribute individuals among the main branches of the service, regiments, etc. An evaluation of the quality of performance depends greatly on the momentary conditions of the commands concerned.

b. In *industry,* the worker is a number rather than an individual. The reaction against this condition is the organization of workers into labor unions. These labor unions to some degree are the natural opponents of the factory owner, the trust, or group of industrialists.

The methods of selecting the leadership groups in industry are, by and large, quite primitive. Chance plays a major part in the selection of industrial leaders. Lacking more accurate means of selection, industrial concerns take the college transcripts of former students to determine the extent of their basic scientific-technical background.

Due to the preference for college-trained personnel, the numerically small intellectual strata of a nation gain influence upon industry which is not entirely justified by their qualities. The wealthy person is too often given preference over a more highly qualified but poorer applicant.

Scientific and technical societies have a certain influence upon selection methods for personnel in scientifically important positions in industry. Yet seen against the totality of the industrial personnel field, the significance of these societies in the selection process is limited.

c. In *science,* particularly in research, the universities and scientific institutes, scientific and technical societies, and even the technical publishing field primarily hold the key to the intellectual qualifications of personnel.

Yet even here the available means for personnel selection are limited in actual practice. A large portion of academic personnel remains unrecognized with respect to their abilities and their potential contributions. This large portion of academic personnel lives, as it were, in the dark and surrounded by complete anonymity.

d. Among the three types of selective systems which we have discussed, the military system of personnel selection is the most extended. In countries with a planned economy like those of the Soviet orbit, the military system of personnel selection is applied with relatively minor changes to the industrial fields and in some ways even to the selection of academic personnel.

However, this method of applying military procedures inevitably undermines progressive trends in production

and also destroys the initiative of the individuals in creating new ways by intellectual and technical means. It seems that the Soviet system is aware of this fact by giving more freedom to individualism — at least in some fields.

Individualism is a main element of progress in the work of science and engineering of the Western world. But on this side there is the danger that the continuously expanding fields of modern science result in a lack of organization of the general approach to progress by science and industry. Some future concentration of efforts is unavoidable in the interest of work economy of the Western nations. This especially applies to personnel policies of research and development.

e. In regard to the personnel policies in military research and development we establish our

THIRD BASIC PRINCIPLE: *Military research and development involves all three vocational types: the scientist, the industrial engineer, and the soldier. A special system of personnel selection must be employed for each of these three groups.*

In order to obtain a workable system of overall personnel guidance in this field, furthermore, it is required that the selective methods applied to each of these personnel groups may have some similar characteristics. This will insure equal standards of personnel qualities within the overall organization of this field, military research and development. We then may introduce a

FOURTH BASIC PRINCIPLE: *To assure harmonious collaboration of all three personnel categories—military, industrial, and scientific—the methods of personnel selection for each of the three types must have certain common characteristics.*

f. Personnel Selection According to Quantity as Compared with that According to Quality:

It is evident from these deliberations that although the "intellectual" selection of personnel is of greater importance to progress in military research and development, certain means of mass selection of personnel must also be adopted. A mixed system of selection will therefore have to be employed.

The best system for selecting personnel according to intellectual performance was developed at the universities and related institutions. The most complete system for handling large masses of personnel for large-scale government projects has been developed by the armed forces. Both personnel selection systems must be jointly adjusted to the requirements of military research and development.

Since such fundamental principles may sound rather abstractly theoretical, we hereby provide the impatient reader with a few examples for the exercise of his imagination:

(a) An officer assigned to military reesarch and development will have to satisfy stated requirements of scientific and technical training and experience. (b) In selecting a research scientist, it is particularly important to arrive at an estimate of his creative ability. The evaluation of his past per-

formance will furnish important clues. The biography of such experts will often disclose whether they can be expected to approach military problems with proper understanding. (c) The successful development engineer must have a broad educational background in order to be widely imaginative in his designs. Industrial experience is another requisite qualification. Also, he must be familiar with the basic military problems of warfare in his particular working field.

At present, these principles of personnel selection are still violated in innumerable instances in most of the larger military countries. The detrimental effects of these inadequacies upon the level of performance of intellectual and material work are unimaginably great.

As long as these principles of personnel selection may still be arbitarily violated, no assurance can be given in regard to a sufficient work performance of the research and development organization concerned.

g. The skilled manual worker

The success of experiments in military research and development often depends on the skill of the manual worker building the test models, instrumentation, etc. Assignments of this sort require very often a true artist of his trade with a generous amount of technical understanding and feeling for his task. First of all, it is necessary to single out skilled workmen of such exceptional qualifications from the immense number of persons engaged in manual trades. They then must be systematically trained to increase their abilities even further and to attain the highest possible degree of work performance.

This is not the proper place for describing the methods of such selection. However it seems appropriate to point out that even among personnel of this type, as well as among personnel of the intellectual and technical leadership strata, the mass selection methods as they are used to screen large numbers of people are quite unsuitable.

Here, too, the use of qualitative means of selection is important. The introduction of such personnel selection methods into military research and development will greatly increase the working economy of these projects.

3. *The Means for Exchanging Experience*

a. Scientific Societies

The intellectual working system represented by scientific societies has been developed over long periods of time. In the last centuries research and its application in technology has grown up very slowly. Public interest was only involved in the realm of national education. Nowadays, in which a remarkable part of the national income is spent for research and technical developments by most of the modern countries, the position of these scientific institutions has changed basically. They have become part of the overall national effort for public welfare and, of course, defense. But oddly enough, mostly their statutes and working methodologies have not been adapted to the new tasks. They participate in the advantages of these developments but they avoid allowing public interests to participate in their guidance. In this way they widely are the lonely survivors of an extinct form of the public life. This particularly applies to their services for military research and development.

Scientific societies are the best foundation for informally establishing an intellectual community of thought and acting within the services, and

even within their single branches which is to include representatives of the government as well as the intellectual and distinct technical worker.

The governmental authorities, on the other hand, to some degree exclude themselves from the sphere of scientific societies by not introducing them in the system of their work and by insisting too strongly on their official channels. In many essential working fields scientific societies nowadays exercise merely a phantom function as advisors to government agencies. However, they are treated by the governments with all external signs of respect. Nevertheless, they are kept apart from the actual sphere of government leadership, particularly in the fields of national defense.

Two reasons are primarily responsible for this: (1) The purely private nature of these societies does not provide the governments with sufficient assurance that military secrets will be kept safe; (2) The traditional mode of operation makes it impossible for them to keep up with the constantly changing technical and scientific requirements of national economy, and defense in particular, with sufficient speed and accuracy.

As science proved its military value, the intellectual and material range of such societies was greatly narrowed. The advent of atomic weapons has entirely annihilated freedom of action in certain main areas of modern science. Many of the government leaders have an inclination to forget the narrow limits of a single person's range of competence. The same is true for many intellectual leaders. They all overlook the fact that leadership in research and development can only come from large and small groups of first-rate experts.

In concluding we then may establish our

FIFTH BASIC PRINCIPLE: *The most important national scientific and technical societies must remain in constant and automatic liaison with the overall government planning agencies.*

Their work programs must become partial projects of the involved parts of the national overall working plan. In defense matters, their work must be incorporated into the military plans as a means of intellectual support.

Their work must also be useful to personnel selection in the field they cover by their activities, for the selection of personnel in military research and development in particular.

b. Scientific Publications

The field of scientific publications edited by the governments and by common institutions of science and engineering such as societies, etc. also requires some reorganization since many of its operating methods have become obsolete.

From 1940 to 1951, in eleven years, the research and development expenditures of the American Government have risen 1500 per cent while the research and development expenditures of the American industry have risen 500 per cent.

In the course of such a trend, an increasing proportion of scientific reports falls under security classification and thus becomes inaccessible to the public. This prevents the use of an in-

creasing part of the scientific literature for purposes of educating personnel. The information reaches only a small selected group. Even later de-classification or down-grading of the scientific information and delayed publication is often prevented by "standard policy." Thus vast parts of scientific experiences gained remain unused. Moreover, the system of qualitative personnel selection for military research and development on the basis of this material is administratively interrupted.

These facts alone prove the necessity for reforms designed to re-unite with greater effectiveness the divergent policies of the government and the body of scientific-technical literature.

This is our task: The reform of the fields of technical literature to fit the new pattern of national life with special attention to the requirements of (1) national defense, and (2) the general requirements of the scientific-technical work of the nation.

CONCLUDING REMARKS

1. Personnel policy of the future in military research and development must attempt to combine the stable elements of the military and governmental personnel systems with the usable elements of personnel policy in industry (for development) and in science (for research).

Only when this goal is attained, or at least some progress is made in this direction, will serious scientists and engineers from the intellectually leading strata consider military research and development as an attractive permanent field of activity.

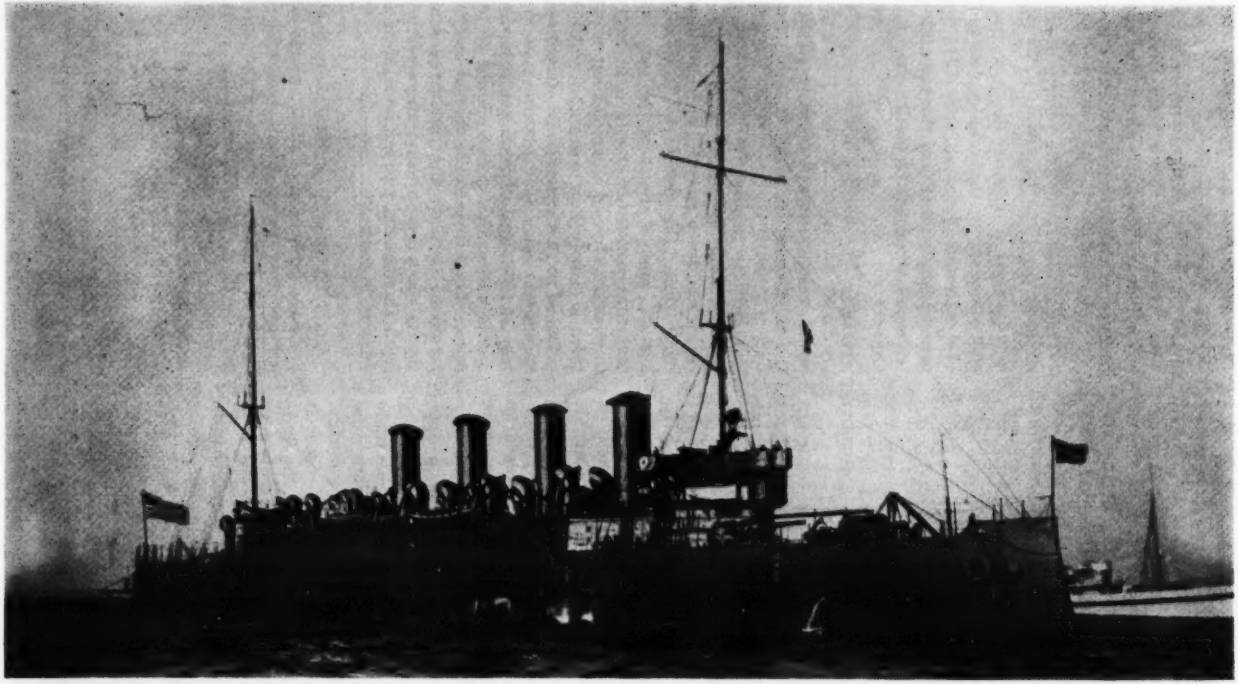
2. The qualitative selection of personnel for positions of leadership is necessarily the task of the intellectually outstanding persons among the military, in science, and in industry, who are engaged in military research and development. Up to now, the finding of talented or even ingenious personalities has largely been left to chance and to personal acquaintance. No basic system is followed. Quite often "pull" enters as a factor.

The present state of qualitative selection of persons for intellectual leadership in military research and development seems to be generally defective. Sometimes it seems to be so inadequate that this military research and development will be hampered in the solution of its tasks.

3. No less detrimental is the effect of subordinating the personnel policies for military research and development into the military personnel system. Such a measure neglects the fact that personnel engaged in military research and development must form a closely knit work group composed of military personnel, scientists, engineers, and administrators as an inseparable unit. Personnel replacements within this group should be an autonomous process. It should be determined only by the inner requirements of the group and the working fields themselves, and not be subject to outside influence.

Today it is still customary to separate the personnel administrators—as a supporting group—from the intellectual and material essence of the military research and development work itself. This is the greatest of all mistakes perpetrated against the basic inner necessities of this field.

4. It is an imperative requirement for military research and development to provide for it a widely independent system for intellectual, material, and administrative guidance combined.



1890 USS Columbia's keel was laid in 1890 and the ship commissioned in 1894. Vertical 3-cylinder triple-expansion reciprocating engines powered the 413-foot -long vessel. She carried a complement of 18 officers and 360 enlisted men.

THE AMERICAN SOCIETY OF NAVAL ENGINEERS

ACKNOWLEDGEMENT

This article, the ninth in a series of articles dealing with engineering societies in America, was published in the May 1954 edition of "General Electric Review." It was written by Captain R. B. Madden, USN, Assistant Secretary-Treasurer of the American Society of Naval Engineers.

Naval engineering—and that includes the broad fields of marine engineering, naval architecture, electrical engineering, electronics engineering, and ship-building—is among the oldest of the various engineering branches. Although some phases, such as electronics engineering, are relatively new, others date back to the days of Noah. Shipbuilding was one of this country's Colonial industries. Shortly after the United States won its independence, the country's first three warships—*Constitution, United States,* and *Constellation* — were designed and constructed under the supervision of naval constructors, as naval engineers were called in those days.

In the 19th century, during the transition period of our Navy from sail power to steam propulsion and from wood ships to iron and steel ships, the profession of naval engineering began to come into its own. Until the turn of the century naval engineering knowledge was largely centered in England and France. But since 1900 the role of American naval engineers has increased to the point that they have become the leaders in their fields.

Naval engineering has broadened considerably with such developments as electronics, electric power, steam turbines, and the use of fuel oil instead of coal. In addition, our warships have improved to the point where they are the finest in the world; since the beginning of World War II, delegation after delegation of foreign warship experts have visited this country for the admitted purpose of determining why our ships are better than theirs.

EDUCATIONAL CONTRIBUTIONS

As early as the last half of the 19th century, naval engineers contributed greatly to the advancement of engineering education in the United States; their efforts affected immeasurably the whole course of technological develop-

ment for many years. By an Act of Congress in 1878, officers of the Engineering Corps of the Navy were assigned to colleges to promote a knowledge of steam engineering and ironship building. During the next 20 years 43 naval engineers were detailed to 52 school assignments. Moreover, many of the officers of the Engineering Corps left the service to take up educational work in a civilian capacity. To indicate the important contribution naval engineering made to engineering education, one need cite the names of but a few of these men: Dr. William F. Durand of Cornell and Stanford, Dr. Robert H. Thurston of Stevens Institute and Sibley College (and first president of the American Society of Mechanical Engineers), Dean Mortimer E. Cooley of the University of Michigan, Dr. Albert A. Michelson of the University of Chicago, and Dr. Ira N. Hollis of Harvard and Worcester Polytechnic Institute.

EARLY ORGANIZATION

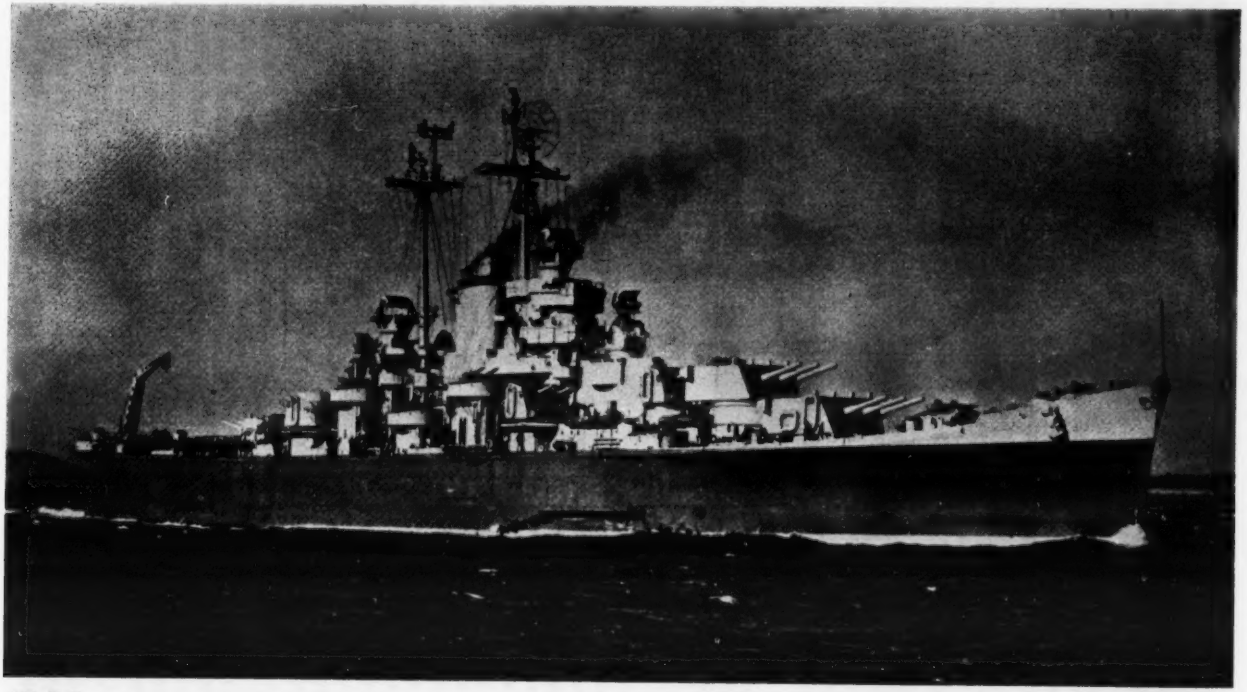
On September 30, 1888, about 20 officers of the Engineering Corps of the Navy met in the Bureau of Steam Engineering. It had been evident that some means for the dissemination of information relative to naval engineering was urgently needed, and the meeting was held to devise ways for the proper presentation and preservation of papers pertaining to debatable subjects in naval engineering. One of the officers present, Past Assistant Engineer A. M. Mattice, proposed that an organization known as the American Society of Naval Engineers be formed for the purpose of promoting naval engineering prestige and efficiency. Under the leadership of Rear Admiral G. W. Baird, the officers present accepted this proposal and decided to issue a quarterly journal to carry out the major purpose of the new society.

Among the individuals most responsible for the development of naval engineering just preceding the formation of ASNE and during the early years of its history, the name of Rear Admiral Benjamin F. Isherwood is outstanding. Admiral Isherwood, the Navy's Engineer-in-Chief during the entire period of the Civil War, is credited with doing more for the advancement of naval engineering since machinery was installed as the propelling power on board naval ships than any other man in this country. His work was the chief impetus for the formation of the Society.

Others who figured prominently in the early years of the ASNE were Chief Engineer Nathan P. Towne, ASNE's first President; Rear Admiral R. S. Griffin, first Secretary and later President of ASNE, World War I Engineer-in-Chief of the Navy, and Chief of the Bureau of Engineering; Walter M. McFarland, later associated with Babcock and Wilcox; Rear Admiral George W. Melville, later President of ASME; Charles H. Manning; Rear Admiral C. W. Dyson, later Secretary and President of ASNE; and Chief Engineer F. G. McKean.

GROWTH AND MEMBERSHIP

By the end of the first three months of the Society's existence, 102 members were on its rolls. During the next year the membership more than doubled, representing the bulk of the officers of the Navy's Engineering Corps.



1944 USS Oregon City was commissioned in 1946, two years after the keel was laid. Steam turbines of 120,000-shp drive this 673-foot-long ship. The vessel's personnel consists of 129 officers and 1840 enlisted men.

The importance of membership in the Society became more and more evident as time went on, not only in the Naval service but in civil life too. Early in ASNE's existence only members of the Naval service were admitted as Active Members. However, the important contribution being made to naval engineering by individuals in civil life, both in a civil service capacity and throughout the marine engineering profession, was recognized by the establishment of the grade of Associate Member. Then in 1922, when the grade of Civil Member was established, 16 Associate Members qualified by engineering experience became Civil Members. At that time the total membership consisted of 800 Naval Members, 16 Civil Members, and 400 Associate Members.

Since 1923 growth of the Society has been gradual but steady. Today the total membership is more than 2700—Naval Members number half, Civil Members nearly 900, and Associate Members about 450.

Eligibility for the three types of ASNE members varies with the status and engineering experience of the individual. Commissioned, ex-commissioned, warrant and ex-warrant officers of the regular Navy, Coast Guard, and Marine Corps, as well as commissioned and warrant officers of the Naval, Coast Guard, or Marine Corps Reserve, are eligible as Naval Members. Persons in civil life who have had eight years of engineering experience —five of them in responsible charge of important work—are eligible as Civil Members. Persons in civil life who are not eligibile for Civil Membership, but who are especially interested in naval or merchant marine matters, can be eligible as Associate Members. And so can commissioned officers of the United States Army or Air Force and of foreign military or naval services.

ASNE JOURNAL

The object of ASNE is the advancement of the art, science, and practice of naval engineering . . .

- By publishing and discussing papers on professional subjects
- By bringing together and publishing the results of experience acquired by engineers in all parts of the world
- By publishing the results of such experimental and other inquiries as may be deemed of value to the advancement of science
- By recording historical events in the lives of engineers.

The decision to publish a quarterly journal made at the organizing meeting in 1888 was to satisfy the impelling demand for bringing within reach of naval engineers valuable technical information and data—possessed by individual officers but not available to the service at large.

The first *Journal* was published in February 1889, and, in addition to notes on recent steam trials and on recent casualties and repairs, its 96 pages contained the following articles:

"Notes on Coals of the Pacific Coast," by Assistant Engineer C. R. Roelker, USN.

"Increase of Horsepower for a Given Speed Due to Foul Condition of Ship's Bottom," by Assistant Engineer W. M. McFarland, USN.

"Data of Some Quadruple Expansion Engines and Their Performances," by Assistant Engineer F. C. Beig, USN.

"Progressive Trials of the Steam Barge of the Commandant of the New York Navy Yard," by Chief Engineer Isherwood, USN.

"Data and Capacity Tests of the High Service Pumping Engines, Washington, DC," by Past Assistant Engineer G. W. Baird, USN.

"Some Problems in Propulsion," by Assistant Engineer W. D. Weaver, USN.

Throughout the Society's 66 years the *Journal* has been published quarterly without a break. Widely referred to and quoted by other publications in its field it now finds its way into practically every area of the globe. Further, many of the articles that have been published in the *Journal* are regarded as valuable reference material by all shipbuilding firms engaged in naval work.

LIMITED ACTIVITIES

The ASNE does not hold professional meetings or conventions, relying on the *Journal* to provide its members with technical knowledge. Instead, it holds an annual business meeting in October in Washington for the presentation of nominations for offices and such other business as may be raised. On January 1 of each year the new officers assume their duties.

In late April or early May the Society holds its annual banquet in Washington. The first banquet, celebrating the 21st anniversary of the Society, was held on May 7, 1909, with 134 members and guests in attendance. Attendance last year was approximately 1700. Each year the banquet attracts top executives and engineers in the shipbuilding and manufacturing industries of this country, as well as leaders in government, besides officers and civilian engineers of the various Armed Services.

ASNE is one of the charter members of the District of Columbia Council of Engineering and Architectural Societies that was organized in 1936.

ROLE OF NAVAL ENGINEERING

Naval engineers are responsible for the research, design and development, construction, alteration, conversion, maintenance, and repair of naval ships including all their machinery and equipment. The 11 naval shipyards—together they form one of the largest industrial organizations in the country—are manned and managed by naval engineers, as are many naval laboratories. In addition, the private shipbuilding industry and many of the country's large and small manufacturing industries include naval engineers among their executives and engineers. And finally, naval engineers are responsible for the operation of the machinery plants of the United States Fleet's many ships.

The wide scope of naval engineering encompasses many fields other than marine engineering, naval architecture, electrical engineering, or electronics. Numerous members are specialists in such fields as chemical, mechanical, industrial, metallurgical, petroleum, and nuclear engineering. Many officers and civilians who are specialists in aeronautical engineering are also members of ASNE, thus indicat-

ing the important relation between the Navy's ships and its aircraft.

Most ASNE members are affiliated with other engineering societies—many elected to high positions. The Society of Naval Architects and Marine Engineers, ASNE's sister society, includes among its officers ASNE members also. At least five presidents of the American Society of Mechanical Engineers have been naval engineers. Other societies have similarly indicated the close relationship between naval and the other engineering fields.

NEEDED CHANGES IN DESIGN OF MILITARY EQUIPMENT

CAPTAIN R. E. W. HARRISON, USNR

THE AUTHOR

was born in Manchester, England, in 1893. Educated Manchester College of Technology. With Royal Engineers, British Army 1914-1919, Egypt, Gallipoli, Sinai, France, Belgium, Industrial Engineering experience includes special apprenticeship and supervisory positions with Churchill Machine Tool Company, England, in the building, design and engineering selling of precision grinding machinery; in 1926 as Director of Engineering, Cincinnati Grinders, Cincinnati Milling Machine Company; 1934 Chief, Machinery Division, U. S. Department of Commerce; 1935 Vice-President Chambersburg Engineering Company; in War II, on staff of Assistant Secretary U.S. Navy, and later as Special Assistant to the Under-Secretary, Registered Mechanical Engineer in Ohio, New York, Pennsylvania, Maryland and District of Columbia. Fellow ASME and Royal Society of Arts; Member other Engineering Societies in USA and Europe. Presently a Consulting Engineer in Washington, D. C.

THE PROBLEM

The forward march of improved technology is inescapable for all of us, but it has handed operators in the field a basic problem. Lacking a workable solution to this problem, it is inevitable that the law of diminishing returns will apply and result in denial of the very advantages sought by the advanced technology.

Our Allies have charged — and at times rightfully so — that our field forces are frequently loaded down with so much highly technical equipment that we are road-bound and immobile. Be that as it may, the fact remains that we have our gadgets and our technological advances, and when we can make them work we are generally spectacularly successful in beating the daylights out of our enemies of that moment.

So, the problem resolves itself: What must be done to make our highly developed technical equipments work, most, if not all of the time, under any and all conditions?

ELEMENTS

Basically there are but two elements with which we must concern ourselves —mechanisms and men. The former are much easier to change than the latter, and it will ease the solution to the problem if we consider the latter first.

The U.S.A. is a democratically operated republic, essentially liberal in its policies when dealing with its people. This is traditional to the point that nothing short of national disaster on a major scale will ever change it. Essentially we make it possible for our young men and women to serve their country, with maximum economic reward, and with minimum interruption in terms of time required, of educational and other pursuits compatible with raising families in line with the highest standards of living.

Intelligent and alert as these young people undoubtedly are, there is a definite limit to their individual and collective capacities to train for and then operate a great many of the gadgets and aids to quick success, with which we equip them when the chips are down for a fight.

The handicap is not a matter of capacity to learn, given the necessary time. The handicap is a matter of time alone. Short term enlistments, combined with relatively short term engagements for the bulk of commissioned personnel, make the task of instructors a herculean one when the figures relating to attrition are cranked into the record.

If there be added to this the cost in dollars of training personnel for 75% of their time in uniform, and then seeing them separated from the service, some measure of the military and fiscal aspects of the problem become so obvious that the need for a change becomes apparent to the point of absolute insistence.

There are those amongst us who proclaim that this educational feeding of the well of national knowledge has its advantages. Conceding these advantages and allowing that they result in some trained reserves and a generally better technologically educated public—So what?

This is no adequate answer to the problem of placing effective forces in the field at short notice. The speed of technological advance nullifies that angle. Well trained to operate or service modern equipment, though John Doe may be in 1953, he is a boot and perhaps a dub when confronted with the counterpart of that equipment in 1958. Military personnel history is replete with the proof of the correctness of this statement.

On the fair assumption that when General Quarters sounds off over the bullhorn for the U.S.A. in the next conflict, there will also be heard the whine and crash of bombs, where do we turn for that element (trained men), which must take the place of the time (to train) which we know we will not have?

DESIGN (THE ONLY RELIABLE SOLUTION)

Better integrated equipment design is the only answer, and to the creative engineer's mission, of generating the original mechanism, there must—repeat, must—be added the virtues of *unitization* and *simplicity*.

PRECEDENT

There exists much excellent and proven precedent in the areas of unitization and simplicity. The domestic refrigerator manufacturer deals in units when his service department reports a functional failure. Most of the older generation will remember the spectacular success of the sealed "turret" unit, which characterized the original GE refrigerator. If anything went wrong, it was but a matter of minutes to substitute a new "turret" and no partially or totally untrained service man was introduced into the picture to complicate and inevitably defeat matters by trying to repair that hermetically sealed mechanism.

Likewise, what optimist has not experienced the frustration resulting from having a garage mechanic try to make a major repair on an automobile engine or transmission? In this field it is rare, indeed, that results can be bettered than those obtained when new or factory rebuilt units are substituted for units which need extensive repairs.

Demonstration of the success of unitized designs is not by any means limited to the examples cited. Diesel electric locomotives are designed to facilitate unitized repairs and even automobile headlights now come with bulb and reflector locked together in a sealed unit.

A great many mechanical equipment manufacturers, recognizing the economic impossibility of supporting service stations manned by skilled men, now distribute through dealers alone and have abandoned, apparently forever, the fiction that skilled detailed service on individual equipment components is either good for the trade or beneficial to the customer.

Wherein lies the parallel between the problem of service on a domestic refrigerator and a tank with a defective engine?

In neither case can the party of prime interest secure completely skilled service and when a unit goes out, the quickest and cheapest way to repair that unit is to trade it in for a new or rebuilt one.

FEASIBILITY

In no field of military technology have forward strides been more rapid than those in electronics. Today's performances are such that the possessor of reliable equipment holds a substantial edge over all opponents; yet, until the recent past, most electronic mechanisms have been a service man's nightmare of tangled wires, unidentified tubes, and transformers, controlled by inadequate switch gear.

It is to the all time credit of the design brains of the electronic industry that the problem has been recognized before the laws of diminishing military returns forced a curtailment in the use of this type of equipment. The reform movement in the direction of unitization has not yet permeated the industry, but the movement is under way and shows signs of adoption as a guiding principle of design. Tinkertoy is making design history.

THE LOGISTICS OF SUPPLY—STANDARDIZATION

Where conflicts exist between the principle of continuity of a certain design and commercial profit, the latter frequently wins out, a not entirely too serious matter when dealing in domestic radio sets or door bells, but when

the problem relates to servicing military equipment in the field, the implications are wider and frought with much danger.

It is a well recognized fact that those industries, most profitable to the stockholders who own them, all possess a definite pattern of conditioned acceptance of the principles of engineering standardization.

Basically, they have accepted the thesis that progressive standardization of design and procedure automatically provides the rungs in the ladder of technological progress.

Quoting the outstanding example existent today, we have the yearly model in automobiles and the progressively standardized processes whereby these models are made more economically each year. For a great many years, this excellent policy resulted in the public availability of better cars each year at no appreciable change in basic price. It was the unfortunate happenstance of the great depression and World War II which disrupted the conditions which made this economic progress possible.

We still have our yearly superior models, but the depressed purchasing power of our money makes the upward steps in purchase price progressively more acute. It should be noted at this time that practically all of the increased cost is nothing more than a true reflection of the proportionately increased cost of labor, production technology advances notwithstanding.

There is great significance in this situation from the military preparedness viewpoint, inasmuch as military equipment costs have skyrocketed at a much greater rate these last twenty years, for the simple reason that while labor hourly costs have doubled and trebled, productive efficiency in military weapons has not advanced at anything like the rate applicable to automobiles, radios, refrigerators and other domestic necessities in great general demand.

This condition, natural and inevitable as it is, represents another valid reason why the economies available through a program of standardized design and production procedures should be exploited to the fullest possible extent.

CONCLUSION

To sum the case up—militarily we are faced with continuing short term enlistments which make it difficult or impossible to train men and women sufficiently to enable them to do an acceptable job of servicing the complicated mechanisms with which we must now fight our wars.

The counter to this condition can be found in the design department, and we need writers of engineering specifications who can visualize in a practical way the unitization of design; i.e., the creation of end products, so assembled that when one unit proves faulty it can be replaced by relatively unskilled help and the mechanism as a whole restored to functional integrity.

Difficult, you say—well, yes not exactly easy—but we have done it for our motor cars, our refrigerators, our washing machines and our domestic radios—all under pressure of economic necessity. So—why not do it for our military equipment?

In the military field we not only need the resulting economy in the cost of servicing, but more importantly we need it to safeguard something infinitely more valuable — our national and individual freedoms.

Think it over, Engineers (civilian and military alike) — our present tanks, guns, radars and sonars, say you've been slipping in a major area even though company balance sheets proclaim you are doing okay in the dollar bracket. That pile of dollars will buy nothing but trouble for you, if we should happen not to win the next fight. The Russians use roubles, not dollars—and in addition, they have their own sweet ways of gaining compliance from manufacturers—roubles or dollars notwithstanding.

TECHNICAL PROGRESS IN MARINE ENGINEERING DURING 1953.

ACKNOWLEDGEMENT

The January 1954 issue of "The Shipbuilder and Marine Engine-Builder' published this staff article.

STEAM RECIPROCATING ENGINES

Steam reciprocating engines have well earned their reputation for reliability and low maintenance costs, and during the past year a most interesting installation has been designed and placed in service. The Great Lakes twin-screw car-ferry *Spartan* is powered by a pair of Skinner Unaflow steeple compounded engines, each developing 4,000 S.H.P. at 130 r.p.m. Steam is supplied by four Foster Wheeler "D"-type boilers (three being capable of maintaining normal full power, while the fourth is on overhaul or stand-by) at a pressure of 450 lb. per sq. in. and 750 deg. F. temperature. Corresponding h.-p. and l.-p. cylinders are arranged co-axially, and, although individually single-acting, each pair together is effectively double-acting and drives one crank. Each engine has four such double cylinders, the liners all being plated on the Van der Horst Porus Krome process, which, it is claimed, reduces the lubrication difficulties, due to the high initial-pressure. The boilers are coal-fired by means of spreader-type stokers, which are conveyor-fed from self-trimming bunkers. The principle factors affecting the machinery choice have, undoubtedly, been the paramount need for reliability in order to maintain a tight schedule, the reduction to a minimum of laid-up time for maintenance, and the abundant supply of comparatively cheap coal.

There has been a continued demand for the more conventional steam reciprocating engines, with live steam reheat, an example of which is the installation in the *Boheme*. This triple-expansion machinery develops 3,900 I.H.P. at 94 r.p.m. in service, and on trials developed 4,500 I.H.P. at 98 r.p.m. The cylinders are arranged in the customary N.E.M. disposition of h.-p., l.-p. and m.-p., giving good balance and maximum accessibility to the cam-actuated poppet-valve gear. The cylinder diameters are 27 in., 44 in. and 76 in., with a stroke of 51 in. In view of the somewhat high rubbing speed (844 ft. per minute), a closed lubricating system is employed for the top-end brasses, oil being pumped by T. & K. lubricators through flexible

pipes attached to the indicator rods. Steam is generated, at a pressure of 220 lb. per sq. in. at a maximum temperature of 750 deg. F., in three Scotch boilers, and the vessel, which is 445 ft. in length and 6,563 tons gross, has a service speed of 12.5 knots, with an oil consumption of 34 tons per day.

STEAM TURBINES AND BOILERS

In the closing paragraph of his paper on "The Application of Research to Marine Turbine Development," Mr. T. W. F. Brown, D.Sc., S.M., expressed the hope "that it will be agreed that this young Association (Pametrada) not only takes part in the stirring of research, but also contributes something to the increase in engineering knowledge in general, and, in particular, to the improvement of marine engineering, so vital to the welfare of the British Isles." The success of Pametrada will be at once acknowledged by all marine engineers, and is, once again, demonstrated by the quality of the papers presented at the conference on steam-turbine research and development, held under the auspices of the Institution of Mechanical Engineers, in March, 1953. The scope of the conference was such that, in an article of this nature, little more can be done than to refer to the titles of the papers presented. They were:—

"Facilities for Full-scale Testing of Marine Turbine Machinery," by Mr. T. W. F. Brown, D.Sc., S.M.;

"The Development of a Marine Steam-turbine Design," by Mr. H. G. Yates, M.A.;

"The Measurement of Specific Steam Consumption," by Mr. M. H. Petty, B.A.;

"Back-to-back Testing of Marine Reduction Gears," by Mr. A. Cameron, Ph.D., B.Sc., and Mr. A. D. Newman, B.Sc.;

"Some Reflections on the Thermal Distortion of Turbine Casings," by Mr. B. J. Terrell, M.B.E., B.Sc. (Eng.);

"The Determination of Natural Resonances in Mechanical Structures," by Mr. O. P. T. Kantorowicz; and

"The Application of Research to Marine Turbine Development," by Mr. T. W. F. Brown, D.Sc., S.M.

Dr. Brown draws attention to the fact that Pametrada, as a research station, has been built round the design department, and, undoubtedly, therein lies one of the reasons for its success. The liaison between research and development is of the closest and is two-way in its nature. In many fields of engineering, there is considerable lag between these two, and even such an authority as Sir Henry Tizard, G.C.B., A.F.C., F.R.S., has expressed an opinion that one of this country's greatest needs is to reduce this lag. It is a source of pride to feel that, where marine turbines are considered, the time lag has been reduced towards vanishing point. Of particular interest in this direction is the paper by Mr. H. G. Yates, in which is illustrated the way in which the 1953 design developed from that of 1945. One of the tables in the last paper vividly demonstrates the interrelation of the many aspects of research in marine turbine machinery which are covered by Pametrada. The results of that work all flow to the design department, and often the design department, by indicating difficulties, stimulate research in new directions.

The turbines of 1953 design are all of double-casing type, whether they are compounded or single-cylinder. By this means, cylinder castings are greatly reduced in weight and complication, and thermal stresses are reduced, as are heat losses. Gashed rotors and impulse blading are used throughout, except in the last few stages of l.-p. turbines, where reaction blading is used (gashing being continued). The impulse diaphragm nozzles are built up from segments constructed of alternate packers and blades, after the fashion of the fixed blading of Parsons reaction turbines. By compounding the astern turbine and carrying the high-pressure section on an overhang, the distance between supports of the inner casing of the high-pressure ahead turbine does not have to be increased, no internal glands have to be provided, and, by arranging a completely separate external casing, there is such freedom for expansion that it can be designed to take the full steam temperature. This is a considerable simplification when maneuvering. The h.-p. section develops about one-third of the total astern power, the remainder being developed in the l.-p. astern turbine—which is housed in a separate inner casing within the low-pressure outer casing. As mentioned, this construction is suitable for high steam temperatures and has the further advantage of reducing the span of the l.-p. turbine bearings, by removing part of the astern blading from the l.-p. turbine.

Although it appears that, in due course, the gas turbine will supplant the steam turbine over an increasing range of power, this will not be for many years and as the flexibility and adaptability of the steam turbine have not yet been fully exploited, considerable research is proceeding in this field. The trend of development is in the direction of higher pressures and temperatures, and the extent to which steam temperatures can be raised seems to depend mainly on the availability of suitable materials. A point will eventually be reached when it will be necessary to consider the use of austenitic steels for such components as blading and superheater steam tubes. This will lead to the problem of welding austenitic-steel tubes to one another and to ferritic-steel tubes outside the superheaters.

In order to provide experience with high-temperature steam in conjunction with high pressure, there has been designed by Pametrada a six-stage impulse turbine representing the h.-p. cylinder of a three cylinder set. The inlet conditions can reach 1,100 lb. per sq. in. at 1,100 deg. F. A boiler using normal residual fuel delivers steam at about 1,200 lb. per sq. in. and 950 deg. F. to a separate, gas-oil fired, second-stage superheater. It is understood that particular attention will be paid to the performance of the special materials used, and that investigations will also incorporate the effect of thermal stressing and distortion of the austenitic-steel casing under changing temperature conditions.

In the search for improved economy, steam temperatures have been rising, and more automatic controls are being used on boilers. With the development of burners which can operate satisfactorily over a wide ratio, single-furnace boilers are being increasingly favored, as they occupy less space and are more easily controlled. These trends are exemplified in the steamship *Nestor*, where the effect of high superheat temperature (950 deg. F.), coupled with low water-inlet temperature (245 deg. F.), is to increase the proportional rate of heat absorption in both economizer and superheater, so that the steam-generating surface is comparatively smaller. The use of furnace water-wall tubes still further

reduces the generating surface and, in this particular boiler, only seven rows are required, all of which have been located before the superheater without reducing the gas temperature at inlet to the superheater below the design figure. In this way, the superheater has been freed from artificial space limitations and is fitted in a position where the economizer is usually found. The astern superheat in the *Nestor* has to be limited to 750 deg. F. (it has not got the overhung h.-p. astern section), and the gas flow in the boilers is controlled by dampers; for astern running, about one-third of the superheater surface is by-passed, the final trimming of the superheat temperature being by means of an air attemperator. No steam is bled from the main turbines, the only source of feed-heating steam being the turbo-generator exhaust.

While the main boilers are naturally circulated, the auxiliary boiler is of La Mont forced-circulated design, fitted with completely-automatic controls. This design permits of considerable saving in weight and gives very flexible operation over the full range of load.

In the main-boiler instrumentation, new equipment has been designed to protect superheater tubes and turbines against damage due to sudden foaming, and to give warning against increasing carry-over of solids. The foam control comprises an electronic low-level unit and a stainless-steel probe fitted within the boiler drum, so that its tip is located at the maximum permissible foam level. As the foam contacts the probe, a low-voltage A.C. circuit is completed which, through amplifiers and relays, energizes an alarm. The solids carry-over is continuously monitored by means of a conductivity cell immersed in a condensed sample of continuously drawn-off steam. As the conductivity rises to some predetermined limit, an alarm is energized and it can be arranged automatically to cut off fuel, feed water and main steam to turbines.

A new test-house has been built and equipped by White's Marine Engineering Co., Ltd., to investigate problems associated with the combustion of liquid fuels. Work on oil-burner design is proceeding, and includes the study of burning oil under high pressure, particular attention being given to air-register design. The experimental furnace can take burners of up to 800 lb. per hour capacity, and the pumping, heating and filtering equipment can handle up to 1½ tons per hour at a pressure of 450 lb. per sq. in., preheated to 300 deg. F. Combustion air can be delivered at the register plate at 20 in. W.G.

By comparing the thicknesses of boiler tubes required by the different classification societies in this country and abroad, Mr. D. W. Crancher, B.Sc., in his paper on "The Thickness of Tubes for Water-tube Boilers," before the North-East Coast Institution of Engineers and Shipbuilders, very clearly directs attention to the wide difference of opinion that exists concerning the optimum thickness of tubes for any particular pressure and diameter. He makes a rational approach to the problem, analyzing the effect of both uniform and non-uniform heat absorption on thermal stress, and, thus, on the total combined stress. Defining the optimum thickness as that which permits the maximum heat obsorption rate for a given pressure, without exceeding a safe working stress, the important conclusion is reached that the optimum thickness occurs when the pressure and thermal stresses are equal, *i.e.*, total stress is twice the pressure stress. A simple design formula, based on this conclusion, is sug-

gested in the paper, and it is to be hoped that the various bodies concerned will give this matter their attention, as the present position of wide divergency should not persist.

The working condition of superheater tubes is becoming increasingly arduous, and, in this connection, Mr. M. G. Gemmill and Mr. J. D. Murray reported in *Iron and Steel* (July, 1953) on some tests they had carried out on five possible superheater-tube steels. They showed that phosphorus both increases the rupture strength and also has a markedly beneficial effect on the resistance to the primary stage of creep up to concentrations of 0.04 per cent., there being some further gain by increasing the content up to 0.06 per cent. The improvement in low-deformation creep strength outweighs the reduction in ductility with which it is accompanied, and it is considered to be an advantage to have the phosphorus content in superheater-tube steels up to the 0.05 per cent. maximum, which is stipulated in many specifications.

Service tests on 12 commercially available alloys, suitable for superheater tubing, which had been reported last year, and which consisted of suspending them in various steam-generating units, have been followed by a set of experiments conducted with the same materials using controlled, synthetic, combustion atmosphere at 1,350 deg. F. The work has been carried out by Mr. C. J. Slunder, Mr. A. M. Hall and Mr. J. H. Jackson, and is reported in the Journal of the American Society of Mechanical Engineers (paper No. 52.A.36). The atmospheres used were of nitrogen, carbon-dioxide and oxygen, with variable quantities of sulphur-dioxide, carbon-monoxide and alkali-metal salts. No attempt was made in these tests to simulate conditions resulting from the combustion of fuel oil with high sulphur and vanadium content. With a few exceptions, the results were in general agreement with the service-test results. A statistical survey of the results showed that an increase of the sulphur-dioxide content from 0.02 per cent. to 0.2 per cent. was significant in increasing the corrosion rate of attack, but neither variation of carbon-monoxide up to 0.1 per cent., nor partial immersion of specimens in alkali-metal salt mixtures appeared to have any significant effect on the corrosion rate.

The use of steam for soot-blowing has always seemed rather a waste of valuable power and, recently, two or three firms have developed cleaning by pneumatic means. In one arrangement, blowers are located at strategic points and are fed from a small air bottle. Air is blown out in "puffs" of one-second duration, the air bottle being charged-up in between puffs. Each soot-blower is supplied in sequence, and, during each puff, a rotation of 17 deg. to 17½ deg. is made, so that each blower discharges about 21 puffs in making a complete revolution (if required), and then the next one takes over. The full blowing cycle for a boiler may thus take about three hours, and will create no soot nuisance on deck. The use of air instead of steam shows a thermal economy, and certainly saves feed water.

Before leaving the subject of boilers, it should be noted that Messrs. Hayward-Tyler & Co., Ltd., have developed a submersible boiler circulating pump, which is at present manufactured to operate in temperatures up to 750 deg. F., and at pressures of up to 3,000 lb. per sq. in. The unit consists of an electric motor, whose windings are submerged in boiler water, and a pump driven by this motor. The pump and motor assembly is housed in a pressure casing, in which all stuffing boxes, me-

chanical seals and couplings are eliminated.

With the advancement of stop-valve conditions, the investigations of the flexibility of steam pipe-lines and the estimation of anchorage loads have to be made with increasing accuracy if maintenance work is to be kept down. In this connection, a very useful summary of methods for analyzing piping-flexibility problems is given by Mr. S. Crocker and Mr. A. McCutchan in the July issue of *Heating, Piping and Air-Conditioning*. Two better qualified authors for such a summary would have been difficult to find. They indicate that straight graphical methods are exceedingly useful when making preliminary layouts, but that analytical methods of greater exactitude are required for a finalized design. Recent data concerning flexibility of corrugated expansion pipes is given in a very useful form by Mr. S. D. George in *Mechanical World* for August, 1953. Both self-equalizing and non-equalizing types are dealt with, the data being given in graphical and tabular form.

As reported by Mr. E. Fuchs, M.A., and Mr. A. J. P. Tucker, M.A., Ph.D. (Transactions of the Institute of Welding, 1953), a technique has been developed which produces high-quality butt welds between pipes, without the use of backing rings. This represents a considerable simplification, as the use of backing rings necessitates pre-heating to prevent constraint and basal cracking, and then requires final machining for its removal. The new technique eliminates these operations. The principal characteristics of the method are as follows:—Electrodes of only 12 S.W.G. are used; current is closely controlled at 80/85 amps., D.C. for ¼-in. to ⅜-in. wall thickness, and at 85/90 amps. for 19/32-in. wall thickness; and a root gap must be provided sufficiently wide to alloy a weaving motion of the electrode and to allow a visual check on the penetration (approximately 1/16 in. for ¼-in. and ⅜-in. wall thickness, and ⅛ in. full for 19/32-in. wall thickness). To ensure this root gap and prevent closing, the joint must be firmly jigged and tack-welded. A chamfer of 30 deg. to 35 deg. is recommended with a root face in excess of 1/16 in. Weaving of the electrode is a most important factor.

DIESEL MACHINERY

Details of two new series of Sulzer engines have been given by Mr. W. Kilchenmann, Dipl. Ing., in his paper before the Institute of Marine Engineers. The R.S.76 series has a bore of 760 mm., a stroke of 1,550 mm., develops 1,000 B.H.P./cylinder at 115 r.p.m., and can be built in units ranging from four to 12 cylinders. The R.S.58 series has a bore of 580 mm., a stroke of 760 mm., develops 520 S.H.P. at 240 r.p.m., and can also be built in units of four to 12 cylinders. Both are of the single-acting, two-stroke cycle type. The R.S.76 range is intended for direct drive and represents the largest cylinder bore and stroke which the manufacturers consider suitable, while the R.S.58 range is primarily intended for geared installations, particularly where headroom is likely to be limited.

Both series are designed to burn residual fuels, and there are several interesting features. An oscillating valve controls the passage between exhaust ports and exhaust manifold. This provides the basis for two advantages.

Firstly, the piston skirt is not required to cover the ports when the

piston is at top-centre, as the valve can prevent escape of scavenge air into the exhaust ports. Thus, the piston and rod can be of normal four-stroke cycle design, which, in turn, permits of the complete separation of crankcase and cylinder, by means of a diaphragm carrying a piston-rod stuffing box, without any undue increase of height. Contamination of lubricating oil in the sump with any sludge-like products, which may pass the piston ring when burning heavy fuel, is thus prevented.

Secondly, the exhaust valve is controlled in such a way that it closes the exhaust ports at the end of the scavenge period, and the after-charging of cylinders up to full scavenge-air pressure can be achieved without the provision of a second row of scavenge ports fitted with no-return valves. The injection timing can be altered while running, both commencement and cut-off being adjustable, so that fuels with varying combustion characteristics can be dealt with. The fuel pumps are situated at cylinder-head level, to reduce to a minimum the length of the high-pressure piping which carries high-viscosity fuel oil between pump and fuel-valve. The injector itself is designed so that the nozzle is particularly well-cooled.

Two R.S.58 nine-cylinder engines are installed in the New Zealand Shipping Company's motorship *Surrey;* they are each rated to develop 4,500 S.H.P. at 225 r.p.m. Each engine drives its pinion through an induction-type electrical coupling, both pinions driving the one main reduction wheel. Such an installation is particularly handy when maneuvering, as, with one engine running ahead and the other astern, the propeller can be turned in either direction merely by exciting the appropriate coupling. This arrangement involves no use of starting air, or waste of time waiting for a shaft to come to standstill.

Geared installations are receiving considerable attention and the following is an interesting proposal for cross-Channel passenger and cargo vessels. The particular owners concerned intend to standardize their machinery as multiples of a particular unit, and the engine-builders have organized a comprehensive servicing system, by means of which replacement engines can be installed at any suitably equipped port in the world. The operation takes only 12 hours, as compared with the two or three weeks usual for the normal overhaul of direct-coupled machinery. The unit chosen is a Napier Deltic marine Diesel, which will be rated at 1,735 S.H.P. Thus, the proposed 6,900-S.H.P. twin-screw installation will consist of two pairs of engines, each pair driving through fluid couplings and a reverse-reduction gear on its appropriate shaft.

The Napier Deltic engine is a triangular two-stroke cycle opposed-piston unit with three crankshafts, and has 18 cylinders of 5⅛ in. bore with a stroke of 7¼ in. It develops 2,500 S.H.P. at a crankshaft speed of 2,000 r.p.m. and a B.M.E.P. of 91.9 lb. per sq. in. The continuous rating is 1,875 S.H.P. at 1,700 r.p.m., with a B.M.E.P. of 81.8 lb. per sq. in., at which condition the piston speed is 2,050 ft. per min. The necessary pumps and filters are integral with the engine, the overall dimensions of which are 10 ft. 11 in. by 6 ft. 2½ in. by 7 ft. 1 in. The power unit weighs 8,725 lb. and the necessary reversing gear weighs a further 1,775 lb., giving a weight of 5.6 lb./S.H.P. at the continuous rating. As the bore and stroke indicate, the components are small enough to allow the use of modern aero-engine materials and manufacturing techniques, and the present-day cost of the power plant is estimated at £21 per S.H.P. (at continuous rating). The engine should

give a smooth turning effort, as a firing stroke occurs at each 20 deg. of crank-angle.

Figures recently quoted in *Hansa*, in which direct-coupled, geared medium-speed and Diesel-electric drives are compared for an output of 2,500 S.H.P. per shaft, indicated the data given in the accompanying Table.

	Direct-coupled.	Geared Medium-speed.	Diesel-electric.
Weight	1	0.57	0.67
Specific fuel consumption, lb/S.H.P./hr.	1	1.065	1.17

Although the medium-speed engines are more noisy than the directly-coupled types, due to the higher frequency, this noise is more easily suppressed.

Another case of standardization is in connection with the Hamburg ferries. Owing to the very large number of maneuvers to be carried out (of the order of 1,000 per day), it has been decided to install Diesel-electric sets developing 300 S.H.P. at 500 r.p.m. The propeller motor runs at 1,250 r.p.m., and is geared down to the propeller shaft, which turns at 180 r.p.m. Hatchways are arranged in the decks above the Diesel generator set, so that it can be removed as a whole, and a replacement unit fitted when overhaul is required.

The Doxford engine is still proving to be among the most popular British-built engines. The accumulator fuel-injection system which has been developed, and to which reference was made last year, has now been fitted in a ship. The motor vessel *British Craftsman*, powered by a Doxford four-cylinder engine developing 3,300 S.H.P. at 108 r.p.m., has been converted from the common-rail system of fuel injection to an accumulator type of system. The system has the simplicity of a jerk-pump arrangement, but allows the use of a much smaller pump shaft. Each fuel pump comprises a pair of opposed pistons. The lower one is operated by a cam with a comparatively gradual rate of rise; while the outer end of the top one is enclosed in a chamber, and is subjected to a steady pressure of 6,000 lb. per sq. in., which is built-up and maintained by a charging pump. The metering control is similar to that of the Bosch pump, the commencement of compression being controlled in the usual manner. As the metered charge of fuel is compressed, the upper piston is raised off its stops against the accumulator pressure; and when the discharge port is uncovered by a groove in the lower piston, the accumulator pressure forces the upper piston back on to its stops, and thus injects the fuel charge into the cylinder *via* a normal spring-loaded valve. This system leads to the elimination of both reversing lever and maneuvering shaft, and has resulted in a two-lever control, one for starting air and the other for fuel. A simplified starting air system has also been introduced, consisting of pneumatically-operated valves in the engine cylinders and a rotary distributor. This latter is a housing with a shuttle revolving in phase with the crankshaft, such that it passes, in correct sequence, ports communicating with the cylinder starting valves.

The first two-stroke cycle, turbo-charged Diesel engine to go to sea has been built by Messrs. Burmeister & Wain. Their six-cylinder engine in the tank ship *Dorthe Mœrsk* has a continuous rating of 7,500 S.H.P. at 115 r.p.m., with a corresponding I.M.E.P. of 113.3 lb. per sq. in., and fuel consumption of 0.337 lb. per S.H.P. per hour. The output of a normally aspirated engine of

the same dimensions has been effectively increased by 35 per cent., and trials have demonstrated that the capacity of pumps and coolers need not be increased.

The Amsterdam firm of Werkspoor, N.V., have now also developed a two-stroke cycle marine Diesel engine, which is supercharged by a Brown-Boveri exhaust turbo-compressor set, run in series with the normal scavenge pumps to deliver the scavenge and supercharging air. The B.M.E.P. is given as 94.6 lb. per sq. in. continuous rating, with a maximum output of 101 lb. per sq. in. The fuel consumption remains the same as when normally aspirated.

Several articles have appeared during the year dealing with the recovery of waste heat from the exhaust gases of Diesel engines, even in the case of supercharged engines, where some of the heat is taken out in driving an exhaust turbine. Marine engineers usually make full use of this heat source, either for distilling water or for raising steam for space heating and hot water. A good guide to the extent of heat recovery available is given by the following figures for steam quantities, which can be raised at 100 lb. per sq. in. (gauge) from water at 120 deg. F. per 1,000 S.H.P. developed:—

(*a*) For two-stroke cycle engines, exhaust temperatures about 550-600 deg. F., 800 lb. per hour.

(*b*) For four-stroke cycle engines, exhaust temperatures about 650-700 deg. F., 1,000 lb. per hour.

A striking example is the Dutch liner *Oranje*. In this vessel the waste heat is used to generate 33,000 lb. of steam per hour at 50 lb. per sq. in. (gauge) for domestic purposes. The propelling machinery consists of three two-stroke cycle main engines, each of 12,500 S.H.P., and the auxiliary exhaust is also led to the waste-heat boilers.

The figures quoted for fuel-bill reductions by Mr. A. G. Arnold, in his paper on the burning of boiler oil in marine Diesel engines, read before the Institute of Marine Engineers in January, 1953, made very clear the attractions of using residual fuels. He gives an account of the successful development of methods for pre-combustion treatment of such fuels, and of a simplified system of compression-operated fuel pump, which completely eliminates camshafts on certain converted two-stroke cycle engines. The *Medon*, which was converted to heavy oil 5½ years ago, is still running satisfactorily. An independent cooling system for fuel valves is always adopted in engines to burn residual fuels, and a strong case is made for using self-cleaning separators for clarifying such oils. Experience has endorsed the policy of limiting the viscosity to 1,500 seconds Redwood No. 1 at 100 deg. F.

It is undoubtedly the case that satisfactory combustion of residual fuels depends on a thorough pre-combustion physical washing and cleaning, and upon appropriate injection conditions, particularly increased atomization. The ease and efficiency of pre-combustion treatment of the very heavy oils can be markedly improved by blending. For example, an addition of only 10 per cent. distillate fuel to a 6,000 seconds fuel can reduce the viscosity to 1,500 seconds, making it much more easy to handle. Even with optimum treatment conditions, however, wear rates must be expected to increase by anything up to 50 per cent. above those obtained with a distillate fuel. At an inspection of the motorship *Auricula*, which occurred in April,

1953, figures were given for wear and length of service for eight cylinder liners. The least wear had occurred in the chrome-plated liner, the maximum mean value being 0.00095 in. per 1,000 hours operation. The adhesion of the chrome plating to the cast-iron was extremely good. The detergent oil, S.3128, used in the cylinders had kept pistons and rings in a cleaner condition than usual, and there was no sign of corrosion attack for which the use of residual fuel could be blamed.

The N.E.M.-Doxford 7,500-S.H.P. engine fitted in the motorship *Raphael* has a special cut-off valve, serving the dual purpose of protecting the cylinders from flooding with fuel in the event of a sticking fuel valve (on common rail), and of reducing the likelihood of carbon deposition on fuel nozzles during periods when the fuel-oil temperature falls. The system readily enables fuel oil to be circulated when the engine is at a standstill.

High jacket temperatures are necessary for the satisfactory combustion of residual fuels, and by using a pressurized system for engine cooling, the United States Coast Guard cutter *Courier* has a jacket temperature of the order of 230 deg. F. The pressure, due to a static head, is 10-15 lb. per sq. in. Steam flashing off in the atmospheric tank is condensed in a sea-water evaporator, the condensate being returned to the cooling system, and the made vapor is condensed and stored. Apart from the waste-heat recovery, it is claimed that the high jacket temperature reduces the fuel consumption by 1 to 4½ per cent., and the lubricating-oil consumption by 10 to 25 per cent., at the same time reducing cylinder-wear rates by 80 per cent. The engine in this particular vessel burns distillate fuel, but the same system could be applied with even greater advantage to an installation running on heavy fuel. Particularly would this be the case for generator engines, as their smaller cylinders present the injectors with a very arduous task. Fuel up to 3,000 seconds Redwood No. 1 at 100 deg. F. has been burnt in engines of auxiliary size, provided it has been preheated so that the viscosity is not more than 130 seconds at the fuel pump and the jacket is not less than 160 deg. F.—a temperature of 230 deg. F. would be even better, and would probably have a still more marked effect on wear rates and lubricating-oil consumption.

The temperature of the fuel-valve nozzle is somewhat critical. Insufficient cooling to this vital region can lead to trouble, because of carbon formation and trumpeting. On the other hand, excessive cooling can lead to external corrosion by pitting due to the local condensation of moisture in the presence of sulphur-dioxide or sulphur-trioxide. A particularly severe case was recently reported, in which the rapid loss of metal from the outer wall of the nozzle body resulted in a leakage of fuel through the wall. Investigations by the British Internal-combustion Engine Research Association have shown that acids will form on surfaces which are exposed to sulphurous combustion products and which have been sufficiently cooled.

An investigation carried out by Mr. D. Flint, Mr. A. W. Lindsay and Mr. R. F. Littlejohn, and reported in the Journal of the Institute of Fuel, for September, 1953, explored the effect of various metallic salt additives to fuel oil on the quantity of sulphur-trioxide in the flue gases. A range of five oils was used, the sulphur content varying from 3.5 per cent. in a heavy fuel oil to 0.7 per cent. in a gas oil. The oils were first of all burnt under carefully controlled conditions without additives. The rate of acid build-up at

various temperatures was recorded. The 3.5 per cent. sulphur oil was then burnt with additions of sodium, calcium and zinc salts, the last mentioned proving the most effective in suppressing the formation of sulphur-trioxide. With good combustion conditions, an addition equivalent to a zinc content of 0.14 per cent. completely suppressed the acid dew-point, and with only 0.07 per cent. zinc equivalent, the sulphur-trioxide was very low. It is reported that the sulphur-trioxide forms more readily as the carbon-di-oxide content decreases (*i.e.*, excess air increases).

In certain circumstances, it is desirable to use perhaps a local solid fuel in place of an oil fuel, and, in such a case, it is most effectively done by using a gas producer in conjunction with an internal-combustion engine. Mr. A. B. Genin, in *Schiffbautechnik*, suggests that the rate of gasification of such a plant can be readily raised to 50 lb. per sq. ft. per hour, and that the required steam can be raised by the engine exhaust gases, a bleed from the gas producer or by oil firing in emergency. The water jacket surrounding the producer can be used as a heat source for the domestic-water supply, and for boiler-feed heating. Figures giving comparisons between tugs equipped with steam machinery, and those in which a gas producer and internal-combustion engine are installed, have shown that, for corresponding conditions, the coal consumption of the steam plants is three times that of the gas producer. The use of Porus Krome cylinder liners, it is claimed, enables the wear to be kept within acceptable limits, despite the high sulphur content of the gas.

The following is given as an example of an oil-engine manufacturers' ingenuity, when faced with shortage of floor space. Having extended their manufacturing range to include eight-cylinder engines, developing 600 S.H.P. at 500 r.p.m., Messrs. Bohn and Köhler found difficulty in providing space for a test-bed. A novel solution was devised. A salvaged 300-ton concrete lighter was used, the hold being divided into two compartments, each fitted with a brake, pumps and instruments, so that two engines could be simultaneously accommodated. There is a plentiful supply of cooling water and no fear of annoyance from vibrations.

Before leaving the subject of internal-combustion machinery, mention should be made that Holford Processes, Ltd., are considering the use of their electrical dehydration plant for ship use, in connection with purification of oil. Such plant is already operating successfully on shore, and typically consists of a vertical cylindrical tank, within which are two suspended cones. These act both as baffles (assisting gravitational separation), and as electrodes for establishing a high-potential electric field. The incoming fluid is preheated and is uniformly distributed within the deflecting cone. Some of the advantages claimed are:—Precipitation of solids and removal of impurities; great flexibility, with application to a wide range of fluids; and low operating cost, with high efficiency. There is said to be no explosion or fire risk.

GAS TURBINES

The first large ship to depend solely on gas-turbine propulsion has been ordered. Messrs. Cammell Laird & Co. (Shipbuilders and Engineers), Ltd., are constructing an 18,000-ton tank ship, to be propelled by gas-turbine electric machinery. A pair of 4,150-H.P. gas turbo-alternators will supply

two propulsion motors (coupled together) thence the propeller shaft through a single-reduction gearing. A steam turbine of 150 H.P. will be used for starting. Auxiliary power is to be supplied by the main gas turbo-alternators, both at sea and in port (while pumping), and Diesel alternator sets will be used when the main turbines are shut down.

A consideration of propulsion requirements of modern ships shows that there is a large group between 5,000 S.H.P. and 10,000 S.H.P. This is a range within which the gas turbine should be most effective, but, until it can successfully burn residual oil, it will be at a serious disadvantage as regards fuel cost in relation to both turbine and Diesel machinery. There is no difficulty in burning these oils, but the products of combustion present two major problems, that of ashing-up of the blades, and that of corrosion by vanadium pentoxide. The first is due to slag particles, which may be completely molten as they enter the turbine and be apt to adhere to the blades; the second problem becomes increasingly difficult as inlet temperatures exceed 1,200 deg. F. Above this temperature, vanadium-pentoxide is molten; it is highly corrosive, and appears to atack all commercially available heat-resisting alloys.

Pametrada and other research organizations are endeavoring to solve these problems. A certain amount of success in reducing corrosion rates has been obtained with additives of the basic metal-oxide type, but they are not of much effect in preventing blade fouling. In this connection, and in view of the reported attack on the blades of the *Auris* turbine, when it had been using residual fuel, it is interesting to note the experience of Mr. P. Draper when investigating the form in which the components of fuel-oil ash appear after combustion (reported in the Transactions of the American Society of Mechanical Engineers, paper 52 A-127). A set of conditions was discovered in which practically no deposits were built-up when working with a fuel which usually produced rapid fouling.

Investigation showed that the exhaust gas contained carbon particles ranging in size from 5 to 59 microns, which represented a combustion loss of just less than 1 per cent., but which carried within them a high proportion of the total ash. These carbon particles were quite different from smoke particles, being about 500 times larger. Their mode of formation is not yet quite certain, but it seems most likely to depend on the relative size of droplet and combustion-chamber size. With a particular relationship of these two, the lighter fuel fractions may evaporate off and the heavier residual fractions may crack on passing through the flame zone, leaving a core of carbon, associated with which will also be the unvolatilized ash. As the incandescent particle reaches the diluent air, it becomes quenched, and thus carries the ash through the turbine in a non-adhesive form; it may act as a mild abrasive. Further work will reveal whether combustion gear and injectors can be made sufficiently flexible to be certain of establishing favorable conditions for a wide range of oils.

The closed cycle permits the burning of residual oils and, at the same time, increases the turbine efficiency at part load, together with weight, complication and first cost. As merchant ships operate for most of the time at full power (in contrast to naval vessels), the attraction of the closed cycle is somewhat reduced, although, whenever a nuclear energy heat source is used in conjunction with a gas tur-

bine, a closed cycle will be necessary. Messrs. Sulzer Brothers Ltd., have under construction, at Winterthur, a 7,500-H.P. closed-cycle set, intended for marine propulsion.

Continued interest is still being shown in both France and the United States in the further development of free-piston type gas generators, as the source of hot, high-pressure gases for marine gas turbines. Several such plants have been at sea for over a year now. The advantages of free-piston machinery are many, and include a good reliability and high thermal efficiency, small weight and space, low maintenance and upkeep, absence of mechanical vibration, and good part-load performance, due to the possible division of load among a number of units that may be shut down as required. One proposed installation comprises eight sets of twin free-piston gas generators, supplying power gas into two turbines, side by side, and coupled mechanically through double-reduction gearing to the propeller shaft. Each set of twin generators consists of two units, mutually out of phase by 180 deg. in order to provide uniform flow.

Further development work in the gas-turbine field is centered on the use of higher gas temperatures, in an endeavor to improve efficiency. The limiting factor is the temperature which the blading can withstand, and considerable effort is being directed towards the development of better materials and improved methods of construction.

Some means of blade cooling is necessary, if really high temperatures are to be used, so that highly-stressed components can be kept at temperatures at which long life is assured. A further advantage of blade cooling in conjunction with a moderate gas temperature is that it may be possible to use the less expensive low-alloy steels, which are not only easier to fabricate, but do not suffer from the disadvantages of highly alloyed austenitic materials, notably a high coefficient of expansion and a low thermal conductivity.

As giving an indication of the size of things to come, it is worth noting that the new Admiralty test-house at the National Gas Turbine Establishment has been equipped with a special reversible Froude hydraulic dynamometer, which can absorb a maximum of 10,000 S.H.P. at any speed between 575 and 1,100 r.p.m. Within a more limited range of speed and power, it is designed to accept an instantaneous reversal of torque. Variation of the load is done by remote control, and, in order to prevent errors due to sluggishness of the transmitting and receiving pistons, the weighing gear is continually oscillated.

TANK-SHIP PROBLEMS

A considerable amount of useful information has been released on the subject of control of internal corrosion of tankers. This is not surprising when an authority such as Mr. John Lamb, O.B.E., gives the following as a conservative estimate for cost of repairs to a 12,000-ton deadweight tanker after eight years of white-oil cargoes —£175,000 for renewals of internal steelwork, and £75,000 for loss of earnings during repair period, making a total of £250,000. Two particularly valuable contributions on this subject are (*a*) a paper read before the North-East Coast Institution of Engineers and Shipbuilders, by Mr. John Lamb, O.B.E., and Mr. E. V. Mathias, B.Sc.,

on "The Preservation of Oil-tanker Hulls," and (*b*) a Symposium published by the American Society of Naval Architects and Marine Engineers.

Part I of the Symposium, entitled "The Nature of Internal Corrosion and its Control," by Mr. William B. Jupp, gives interesting data concerning wastage, length of service and loading history. Methods of reducing corrosion are discussed, and costs of such corrective measures are estimated. As a final conclusion, the importance of the early protection of particularly vulnerable points is emphasized, together with the desirability of reducing salt-water tank-cleaning to a minimum.

When discussing "Inhibitors in Cargo" (Part II. of the Symposium), Mr. J. V. C. Malcolmson, Mr. W. S. Quimby, Miss Gwendolyn D. Pingrey and Mr. J. C. D. Ousterhout, give an account of both laboratory work and ship experiments that were carried out using oil-soluble inhibitors. Particularly good results were obtained with an inhibitor named Santolene-C, when used at a concentration of 42 parts per million in cargoes of premium petrol, kerosine, furnace oil and Diesel fuel.

Considering protection by surface coatings, Mr. Lamb and Mr. Mathias concluded that a general-purpose coating, giving protection over a long period, was very difficult if not impossible to achieve; the difficulty being added to by the bulk transport of coal-tar benzole, and the increasing trade in petroleum chemicals and other such products which are often powerful solvents.

Atmosphere control has been demonstrated to give considerable protection, and, while still permitting the salt-water cleaning of tanks, it is most effective in tanks which are never ballasted. The use of chemical inhibitors applied by means of a fresh-water wash is completely restrictive, and entails the complete exclusion of salt-water from the tanks, both for washing and for ballast. Considerable quantities of chemicals (sodium nitrite for inhibition plus caustic soda for oil removal) and of fresh-water must also be carried and be available at terminal ports. Both dehumidification and chemical inhibition restrict the ballast disposition, but, provided this is accepted, figures indicate that both are economic propositions.

For tests on the use of cathodic protective methods, only the use of expendable electrodes, such as magnesium, is suitable for tankers, owing to the danger of a possible current discharge under explosive conditions, if non-expendable electrodes with an impressed current are used. Initial results with magnesium electrodes are encouraging. In contrast with the foregoing two methods of protection, cathodic protection is only effective in stripping-off old scale and depositing a protective coating when used in the presence of an electrolyte—in this case, sea-water—so that all compartments to be protected in this fashion must be ballasted at reasonably frequent intervals. A program of "staggering" on alternate voyages is a possible solution. Particularly attractive is the simplicity and flexibility of this method, with its total lack of auxiliary equipment, special fittings and special techniques.

It would seem that a dual system, such as dehumidification for nonballasted tanks, and cathodic protection, with sacrificial anodes, for the ballasted tanks, may provide a satisfactory solution. Certain American tankers are using cathodic protection

for ballasted tanks and inhibited-water washing for non-ballasted tanks.

The problem of heating-coil corrosion would seem to have been mastered by changing from mild-steel to cast-iron coils. The first ship to be fitted with cast-iron heating coils, the *Amastra,* was recently examined and, after six years' service, the coils were still in use and showed no sign of pitting or corrosion. It is considered that the extra cost of fitting the cast-iron coils could be written off after two years.

The problem of external corrosion is one that is common to all ships, but certain tanker companies have carried out considerable research into protective measures. In the paper mentioned in the foregoing, Mr. Lamb and Mr. Mathias presented a very strong case for the complete removal of mill-scale from hulls of new ships, prior to the application of the first coat of priming paint. Particularly good results were obtained by the flame-cleaning of plates, followed by the application of the first coat of paint to the still warm surface. In this connection, the use of cathodic protection with permanent graphite anodes and an impressed low-voltage current has been successful. Tests carried out on three tugs, about 70 ft. in length, showed that, in order to get uniform protection, it was necessary to fix the graphite anodes on an insulated patch on the ship's hull. Paint was unsuitable as an insulator, vulcanized rubber was very good but expensive, and, finally, flame-sprayed polythene was used. The trials proved that the method was effective. For these tugs, the protecting current was 20 amperes at 6 volts. The depot ship, *Shell Quest,* intended for the search for under-water oil in the Persian Gulf, is to be similarly protected. The protective voltage will be generated by special-low-voltage generators, and it is estimated that the power absorbed will be 2 kW.

In order to assist the rapid ventilation of tanks and of pump rooms, the motorship *Irvingbrooke* carries a portable ventilating unit. The device consists of a flame-proof, three-phase, induction motor, driving a light-alloy fan, and the whole is fitted in a portable trunk. The overall weight of the unit is 80 lb. and its capacity is 105,000 cu. ft. per hour. The trunk can be fixed to the coaming of a manhole or in a Butterworth opening, and air is blown at high pressure against the tank bottom, from which it is deflected in all directions, scavenging and purifying the atmosphere. A.C. motors are used, since a flame-proof motor of this type only weighs about one-third as much as the corresponding D.C. motor—the light-alloy fan also affords protection against sparking. A tank with a capacity of 35,000 cu ft. can be sufficiently ventilated in two hours, to permit of entry.

A larger type of plant altogether, which can be fitted in special tenders, has been developed by British Wheeler Process, Ltd. The tenders are equipped with powerful vacuum pumps, and large tanks which are exhausted. From these tanks, flexible suction hoses, fitted with special nozzles, are lowered into the tanks that are to be cleared, and all the gases can be drawn off. Sludge can be sucked out in the same way, although initial steaming is sometimes necessary. The tenders are 150 ft. long, and are self-propelled, for mooring alongside vessels.

For dealing with a mixture of oil and water, White's Engineering Co., Ltd., have developed a method of separation which is independent of the specific gravities of the liquids being separated. Use is made of their differing dielectric properties, two probes

being inserted in the oil chamber at the desired upper and lower water levels. The two electrical condensers thus formed by each probe, the tank wall and the liquid dielectric, are connected to an alternating voltage of radio frequency, and the difference in the circuit characteristics is used to control the discharge valves, so that oil and water are not discharged together. A test showed the discharge to contain only 1.7 parts per million of oil.

The turbo-electric steamship *Helix* is a good example of a modern tanker, fitted with many recent developments. The main machinery is turbo-electric of standard design; but, in order to reduce the frequency of the cleaning the fire surfaces of the boilers, the fuel oil is cleaned and purified before it enters the furnaces, in a manner similar to that which has been adopted, so successfully, for preparing such oils for use in Diesel engines.

Several devices are used to reduce the fire hazard. For example, spaces in which naked lights are normally used for working a ship, are pressurized to prevent ingress of explosive gases. Gas detectors give audible warning of dangerous conditions, and filters, capable of separating petroleum gas from air, can be arranged to come in automatically, thus giving time in which all naked lights can be extinguished. A small but important point are the cargo strainer boxes, which can be opened up and cleaned without the use of tools, thus eliminating a possible ignition due to sparks.

By arranging the steam turbine-driven centrifugal cargo pumps vertically, with the driving units on a flat in the engine-room, 18 ft. above the keel, the risk of petroleum entering the engine-room is reduced to the chance of the pump room becoming completely flooded, and again considerably reduces the explosion hazard. The output of the cargo pumps is controlled by means of compressed-air loaded relief valves—a method of control which is both simple and sensitive.

MISCELLANEOUS

Fishing Craft.—

The number of Diesel-driven trawlers is steadily increasing, as owners become convinced of the real fuel economy to be derived, and the Admiralty have now placed an order (on behalf of the Department of Scientific and Industrial Research) for a Diesel-electric trawler for fishery research. She will be powered by four Meadows six-cylinder Diesel engines, each with a continuous rating of 200 S.H.P. at 400 r.p.m., and each of which is flexibly-coupled to a 125-kW. constant-current generator. The propeller shaft is driven by a double-unit motor with an output of 600 S.H.P. at 200 r.p.m. Two 75-H.P. motors drive the trawl winch through bevel gearing; they are of constant-current type, with speed regulation of 1,000 r.p.m. at full load to 1,750 r.p.m. at light load, and can withstand a stalled torque of 1½ times full load for 30 minutes, without overheating. The propulsion motor is controlled, from either bridge or engine-room, by a metadyne-exciter circuit. Auxiliary current is generated at 220 volts by two 135-kW. level compounded machines, driven by two Diesel engines of the same type as the main propulsion motors.

Unusual refrigerating equipment is installed in the motor trawler *Delaware*. It is an experimental installation, and is intended to explore the possibilities of freezing fish, as caught,

for later processing ashore. A 23-ton ammonia absorption machine is used for the freezing and cold storage of the fish. After initial sorting for size, the fish are passed through a brine tank (at 5 deg. F.) in steel meshed baskets carried on continuous traveling chains. The frozen fish are unloaded from the baskets by hand and discharged along light-metal chutes into the holds for storing, the temperature in the holds being kept at 0 deg. F. by means of grids circulated with chilled mixtures of ethanol and water. The capacity is 1,000 lb. of fish per hour.

In connection with a more normal method of handling fish, Mr. W. A. MacCallum has given the results of six years' investigations in Canadian trawlers, and concludes that metal-lined fish-holds are superior to wood-lined ones. He states that fish packed in ice can be completely protected in metal-jacketed holds, if chilled air is circulated in the jacket space and no "hot" spots appear.

Cargo-handling.—

At the October meeting in London, of the International Cargo Handling Co-ordination Association, it was forecast packing of goods at the factory into containers as unit loads, or on standardized pallets. As an example of the last-mentioned, an instance was quoted where 70,000 cases of liquid cargo were loaded on to about 1,800 pallets—a 30 per cent. increase in efficiency was noted during loading operations, together with economy of stowage space, economy of labor and almost complete elimination of lost and broken cases.

The motorship *Hornelen* (152 ft.) is the first Norwegian ship to be designed for carrying palleted cargo. The vessel has A.C. auxiliaries and is equipped with hydraulic deck machinery. As the pallets are dropped into the holds, a one-man electric truck finally positions them.

The unit loads referred to in the foregoing will not necessarily be only bulk cargo, as a refrigerated-cargo container constructed of aluminum has recently been developed in the United States. It can be carried on a specially designed road trailer, from which it is loaded, complete with cargo, into the ship's hold. They are designed to pack one on top of the other and each has a complete, self-contained refrigerator unit. The cubic capacity is 1,545 cu. ft., the tare weight is 4,630 lb., and the net weight which can be carried is 50,000 lb.

A scheme has been patented by Messrs. R. & H. Green and Silley Weir, Ltd., for the construction of dual-purpose deep tanks, to carry either fluid or dry cargo. The tanks are to be provided with flexible, concertina-like inner lining (made of an impregnated fabric), carried on adjustable square tubular frames. When carrying liquid cargo, the lining is expanded to just the right height, so that there is no air space and, consequently, no swashing. When used for dry cargo, the inner container collapses and is protected by a cover mounted on a frame, allowing cargo to be loaded into the tank in the normal way. The metal parts are to be made of aluminum alloy.

Several bulk-cargo vessels have been made self-unloading, typical of which is the bauxite-carrier *Carl Schmedeman*. The four cargo holds for bauxite are served by two hatchways, 34 ft. by 23 ft. 7½ in., having MacGregor sliding covers, controlled by two 2-ton winches. Conveyor belts are fitted below the bottom angles of the W-shaped hold bottoms, and the self-unloading gear is designed to discharge a cargo of 12,500 tons within nine

hours. A central control station provides independent control for each conveyor.

In contrast, the short-sea trader *Milo* (Bristol Channel to the Continent) has no cargo-handling gear at all, and will rely completely on shore cranes at the ports on her route.

Transmission Gearing.—

In his paper entitled "A Now Look at the Scoring Phenomena of Gears," Mr. W. B. Kelly (in the Transactions of the Society of Automotive Engineers) approached the problem of scoring from first principles, taking into account factors affecting the conversion of frictional energy into heat at the surface of gear teeth, their geometry, surface finish and stiffness. The hypothesis, which is developed to explain the failure of straight mineral oils to prevent scoring, is found to give good correlation of the scoring test results, both from actual gears and from ball and roller test machines. The various types of scoring are discussed, and methods of design for higher scoring resistance are also indicated.

In connection with the pitting of gear wheels, Professor Dr.-Ing. G. Niemann and Dr.-Ing H. Glaubiz have undertaken certain work, which is reported in *Zeitschrift des Vereines Deutscher Ingenieure* for the 21st February, 1953.

The results of the tests on the reproducibility of pitting conditions are given, and it is shown that, under the same operating conditions, pitting always commenced during the same load stage. It is also clearly demonstrated that modification of tooth form to give higher sliding velocities on tooth flanks appreciably reduced the load at which pitting commenced. The use of high-pressure and hypoid oils increases the limiting load considerably, and can be relied on to stop and partly remove pitting, which commences when the gears are lubricated with mineral oil at a load within this raised limit. Running-in with hypoid oil, and operating with mineral oil, increase the limiting load appreciably above that obtained when mineral-oil lubrication is used for both running-in and for operation.

Electrical Installations.—A.C. versus D.C.—

In an article in *The Shipping World* of the 7th October, Mr. H. J. D. Thompson compared the use of A.C. and D.C. on board tank vessels, and pointed out that the inherently greater simplicity of the A.C. system, with its possibility of direct on-line starting of motors, is partly offset by the need to provide extra generating capacity (12 to 20 per cent. increase on the equivalent D.C. system), owing to a combination of the lower efficiency of A.C. machinery and its inferior starting characteristics. The high starting currents associated with A.C. motors can cause marked depression of voltage in an A.C. network, and this depression must be limited as far as possible, as the torque of an induction motor is proportional to the square of the impressed voltage. Figures are quoted in a comparison of running costs of generator plants for A.C. and D.C. tanker-systems, and it is estimated that the fuel-saving of a D.C. system is 1½ per cent. in the case of a 32,000-ton tanker and 2¾ per cent. for an 18,000-ton tanker.

Mention is also made in this article of an extremely interesting 25 kVA Diesel-alternator set, which is self-excited through selenium rectifiers and having a voltage regulation of 1½ per cent. over a speed variation of 4½ per cent.

Mr. D. Pust, in *Schiff und Hafen*, also made a detailed comparison between an existing D.C. installation and a comparable A.C. installation for a refrigerated vessel of 3,000 tons gross, such as the motorship *Quartole*. The comparison was mainly from the point of view of first cost, and, for this small size of vessel, the A.C. system would reduce the installation cost by about 7 per cent. and the weight by about 9½ per cent.

Chemical Cleaning.—

Chemical cleaning of heat exchangers has, for some time, been accepted as a rapid and effective method of cleaning and scaling heat-transfer surfaces, provided it is carried out with proper care and attention. The following two cases illustrate new applications of this method, which have been noticed during the past 12 months.

Trichlorethylene and steam are now often used for cleaning oily or greasy heat-exchangers. Steam is first of all used to vaporize the trichlorethylene, which dissolves and cleans off the grease. Later, the steam is admitted to the cleaned space and displaces the solvent from the heat-exchanger surfaces.

A 10 per cent. solution of hydrochloric acid has been used, with success, in descaling a Foster Wheeler two-shell type of evaporator having a capacity of 100 tons per day. After six months' service, the cleaning took only eight hours, and was considered to be more effective than scraping.

Deck Scrubbers.—

In connection with a different method of cleaning, it is noted that at least two types of mechanical deck scrubbers are being manufactured in Britain, one of which can be safely operated with water splashing over it. They are multi-purpose machines, with many different attachments, including one for holystoning decks. The circular movement is not found to damage the caulking or raise the grain, as sometimes happens when decks are hand-scrubbed and holystoned.

ATOMIC PROPULSION

In the Transactions of the Institute of Marine Engineers, for April, 1953, there appeared a paper entitled "Atomic Propulsion—with special reference to Marine Propulsion," written by Sir John Cockcroft, C.B.E., Ph.D., M.Sc. (Tech.), F.R.S. It was pointed out in this contribution that, in the early days of marine nuclear propulsion, the heat generated in the reactor will most probably be used to generate steam and thus replace oil-burning equipment of conventional power units. A marine reactor will be subject to limitations of weight and size, while, in addition to the technical problems associated with nuclear energy, there is the question of economics. The capital costs of a nuclear propulsion unit are estimated to be about three times that of conventional machinery, while fuel costs may be of the order of 2d. per S.H.P.-hour. Neither of these costs are particularly attractive, despite the important advantage of extending the period between refuellings. It seems certain therefore, that, until these figures can be modified, atomic propulsion projects will be confined to combat ships of the atomically-minded countries.

"PERMOBILITY" A NEW CRITERIA FOR ARRANGEMENT OF NAVAL MACHINERY

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INTRODUCTION

Warship design is an interesting and highly advanced science, and any good marine library is full of technical literature on the subject. However, a review of this material soon discloses that very little information is available concerning the machinery arrangement aspects of combatant vessel design. For example, an excellent treatise of over two hundred pages relating to basic warship design devotes less than two pages to machinery arrangement problems. Similarly, an authoritative two volume work of over one thousand pages relating to marine engineering allots less than twelve pages (and most of this is pictorial) to the subject. This situation would seem to suggest that naval machinery arrangement is either an extremely simple or a very unimportant subject. However, it is difficult to reconcile either of the foregoing conclusions with current machinery arrangement practice.

In the design of major combatant vessels it is customary to detail several dozen alternate machinery arrangements for purposes of comparative evaluation. These design alternatives often reflect only a re-arrangement of the same plant components within the confines of the same hull configuration. The very number of such studies is indicative of the degree of importance accorded machinery arrangements. At the same time, the variety of arrangement solutions and the difficulty experienced in evaluating and selecting the optimum design serve to emphasize a lack of specific machinery arrangement objectives.

It is clear that an arrangement is supposed to confer something special on a design, and that "something" is considered highly important. What? That is the question. Perhaps one might be inclined to merely enumerate such conventional yardsticks as minimum weight and space and maximum simplicity and reliability. Yet, this "something" is basically none of these features. After all, they apply equally well to the design of non-combatant vessels, and moreover, they are not altogether achieved or sometimes even achievable simply by arrangement artifices in any substantial degree. More often such features are a function of the type of power plant and the inherent characteristics of the components involved. Only one thing is certain, as is well illustrated by the vagaries of modern arrangement design practice, namely: there are no universally accepted naval machinery arrangement criteria.

The purpose of this paper, therefore, is to seek to establish just what it is that the combatant vessel machinery arrangement designer can confer on an overall ship design, and to evolve practical guiding principles which will better enable him to fulfill this primary mission. Such principles should obviate any necessity for developing an undue number of alternate designs, and should facilitate the ultimate selection of the optimum machinery arrangement.

In the interest of simplicity the scope of the following analysis is limited to a consideration of major combatant vessels. The latter term as used herein connotes vessels having four propulsion shafts, with a minimum of forty thousand horsepower per shaft, and utilizing steam turbine—reduction gear drive. As these limitations may appear overly restrictive, it is perhaps important to emphasize that the ascendency of sea-borne airpower justifies the accent on the larger vessel type, and the turbine-gear plant still reigns supreme in the specified power range.

WARSHIPS EXIST FOR WAR

It is manifest that combat efficiency or military usefulness is the prime requisite of warships. The only return on the tremendous investment that a warship represents is its performance in battle. No competent naval designer would deny the validity of these propositions. Yet, machinery arrangement designers (whether consciously or sub-consciously, and whether voluntarily or by virtue of real or imagined pressures exerted by other participants in overall ship design) apparently incline to a belief that such fundamentals have little or no application within their sphere of responsibility. The uncertainty which pervades arrangement studies and the ultimate evaluation of alternate solutions is ample testimony to the aptness of the foregoing assertion. Yet, it is not merely difficult to evaluate naval machinery arrangements without regard to inherent and varying degrees of battle endurance—it is impossible. An evaluation on any other basis denies or ignores the very purpose of the vessel and is utterly meaningless.

The primary objective of the propulsion plant designer is therefore obvious. He must attempt to provide the plant layout that will assure the maximum degree of continued vessel mobility, by arranging plant components so as to minimize the disrupting effects of battle casualties on machinery, electrical, and piping installations. This fundamental characteristic unique to combatant ship design shall be designated by the composite term "permobility."

"PERMOBILITY," A NEW CONCEPT

The word "permobility" is intended to denote the characteristic of permanent or enduring vessel mobility as a function of the machinery arrangement in the face of always imminent, if not inevitable, war damage. At the same time, the term is intended to connote the battle endurance characteristics of the electrical power generating unit arrangements, in virtue of their vital relation not only to propulsion auxiliaries, but to the offensive weapons and damage control facilities in a ship. With this understanding of the term, it is easy to justify the contention that permobility should be the essential basis for evaluating alternate machinery arrangements. For example, in the recent World War, two out of every five vessels that were hit suffered propulsion damage, but only one out of every seven vessels suffering such damage were lost. On the other hand, two out of every three vessels that were immobilized were lost. It is thus obvious that permobility is not some abstract objective, but is fundamental to the continued usefulness and very existence of the ship itself.

The foregoing observations serve only to provide an overall objective. To concede that the paramount concern of the arrangement engineer is permobility actually solves nothing. We are then confronted with the even more perplexing problem of determining the practical attributes of permobility. This problem might best be resolved by resorting to the time-tested process of elimination, considering the nature of the arrangement engineer's contribution to overall ship design. It is manifest that he is essentially concerned with locating given components within the confines of a given hull configuration. Yet, his problems are not fundamentally a question of either the relative locations of components or the conservation of space. New components are oriented in accordance with their function in the plant cycle. Smaller components are simply alloted proportionately less space; the clearance margin being held more or less constant at the personnel access minimum. In neither case does the arrangement engineer have much design latitude.

The foregoing observations suggest that the arrangement of components within a machinery space is not a factor in permobility. This conclusion is further confirmed by war experience on other grounds. For example, there is not one recorded instance in which a propulsion unit remained operable after a direct hit within the space in which it was located. It is also significant to note that it was a direct machinery space hit which caused disruption of propulsion in seven cases out of ten.

MACHINERY COMPARTMENTATION, THE BASIS OF PERMOBILITY

It would seem that the machinery spaces proper are the major weakspot in the propulsion system, rather than external appendages such as shafting, uptakes, propellers, and combustion air supply systems. It would further appear that the arrangement of propulsion components within a space is of relatively minor significance, since a hit space is a lost space. The inescapable conclusion is that the compartmentation of machinery is far more important than the arrangement of machinery within compartments. Machinery box compartmentation is

therefore the fundamental characteristic or attribute of permobility.

The foregoing conclusion brings the arrangement engineer into direct contact (and too often, into conflict) with the naval architect. The latter is, of course, vitally concerned with ship structure and compartmentation as they are factors in strength, stability, and water-tight integrity. This situation serves, in part, to explain the arrangement engineer's inability to be precise and decisive in recommending a particular arrangement as the optimum. He is at best reluctant to confirm his preferences due to an unfounded suspicion that he might be trespassing in the domain of the naval architect. Of course the latter sometimes (and quite unjustifiably) encourages this doubt.

The arrangement engineer accordingly takes his cue from the hull designer, who all too often regards him as both an unfrocked artist and a fugitive from science. This situation sometimes keeps naval architects happy. Rarely, and only accidentally, does it result in an optimum machinery arrangement from a machinery arrangement point of view. However, the engineer is always able to salvage his professional honor by subscribing to two very valid propositions, namely: all ship design is necessarily founded upon compromise, and all of the alternate machinery arrangements proposed are fundamentally sound and feasible. Nevertheless, one of the collateral objectives in this presentation shall be to indicate and emphasize that the machinery arrangement engineer has an equally vital interest in and responsibility for machinery box compartmentation, apart from those aspects of ship sub-division admittedly wholly within the purview of the naval architect.

CRITERIA FOR MACHINERY COMPARTMENTATION—

Now another question must be resolved. What compartmentation criteria are to be applied by the arrangement engineer in order to achieve an arrangement incorporating maximum permobility? As was intended, the very nature of the word "permobility" suggests that emphasis should be placed on propulsion components.

It is obvious that each propulsion unit should be self-sufficient and independent of all other propulsion units. It is also fairly evident that each propulsion unit should be accommodated in the minimum practicable fore and aft length. This follows from the fact that length is the only really variable compartment dimension (height and breadth being substantially "fixed" in a given design), and is accordingly a measure of the individual propulsion unit target expanse. If disruption of propulsion is predominantly the result of a direct hit, then it is highly important that the target expanse of the propulsion unit be minimized. Finally, it is highly desirable that compartments containing propulsion units be separated from each other by less vital auxiliary spaces. Thus, and in the order of their relative importance, the three basic criteria for propulsion units are—keep them isolated, keep them short, and keep them separated one from the other.

These propulsion arrangement criteria all operate to make a combined main machinery space (i.e., a single compartment containing a complete propulsion unit) fundamentally superior to an arrangement in which the boilers and turbines comprising a pro-

pulsion unit are located in separate compartments. As regards isolation, there is a compelling temptation to provide certain piping connections in both directions (fore and aft) from a boiler room flanked longitudinally by propulsion turbines. This violation of the principle of isolation is made palatable by noting its "improved flexibility." Still, it cannot be stated too emphatically that this type of flexibility is entirely incompatible with isolation, and isolation of propulsion units is a fundamental requisite. If it is flexibility that we want, we should put all four propulsion units in one big common space. Let's face it, flexibility (and here we are speaking only in regard to propulsion units and of a four shaft ship) is a Pandora's box.

It is the same with propulsion unit compartment lengths. A fireroom/engineroom arrangement will always require more length per propulsion unit (on the order of twenty feet for the ship type under consideration) than a combined main machinery room type of arrangement. To be sure, the respective lengths of the fireroom and enginerooms will each be less than the length of the combined machinery room, but we are discussing permobility. This means we are considering the overall length of the propulsion unit. Compartmentation only enters into consideration because the combined space results in less propulsion unit length (and therefore presents less expanse of vulnerable target area) than is required for the two comparable separate spaces of the fireroom/engineroom arrangement.

SEPARATION, A FUNCTION OF BOX LENGTH—

Finally, there is the question of separation. Separation can be discussed intelligently only in connection with overall machinery box lengths. We shall arbitrarily assume the overall length of the separate fireroom/engineroom arrangement as the standard of comparison. The reason for this choice is that for a given machinery plant, a combined space arrangement can always be developed that will require less overall length than the separate fireroom/engineroom arrangement of the same plant. This follows from the fact that the combined space design permits a more compact arrangement of the propulsion unit itself, and entails such incidental but cumulative savings in space as result from shorter piping leads; less piping; fewer valves (as occasioned by the absence of bulkhead penetrations and associated bulkhead cut-out valves in major piping systems); the adequacy of four in lieu of eight propulsion control centers; less necessity for duplicating instruments, controls, and communications equipment; better utilization of space permitted by locating boilers face-to-face with a common tube-pulling area; fewer bulkheads, and resulting less personnel clearance requirements between equipment and bulkheads; and less space sacrificed to compartment access provisions.

Now, as we previously implied anent the discussion of length, the overall length of four combined machinery rooms will be on the order of a total of eighty feet less than the overall length of the eight compartments required for the comparable separate fireroom/engineroom arrangement. For the latter arrangement we shall further assume that all compartments are of equal length, and that this length is increased as necessary to accommodate all the required propulsion and auxiliary machinery. Thus, if we assume the same overall box length when we come to considering com-

bined machinery room arrangements, we note that each pair of propulsion units may be separated by a non-vital auxiliary machinery room, each of which will be on the order of twenty seven feet long. The eminent superiority of the combined space arrangement on the basis of inherent permobility (in addition to the space-saving advantages previously noted) is then obvious. The degree of propulsion unit isolation is identical for the two arrangements, but the combined space arrangement offers the dual advantages of less propulsion unit length, and considerable propulsion unit separation.

Of course, if we provided comparable separation in the fireroom/engineroom arrangement, then its overall vulnerable machinery box length would increase proportionately. Still, for equivalent machinery box lengths, the fireroom/engineroom arrangement provides no separation of propulsion units. It is perhaps unnecessary to note that equivalent overall machinery box length is the only valid basis for a comparison of alternative machinery arrangements. After all, machinery box length reflects the pre-empted ship volume alloted to the machinery plant, and we certainly desire the optimum machinery arrangement (permobility-wise) for any given penalty in ship volume surrendered for accommodating the machinery plant.

COMBINED SPACE ARRANGEMENT ALTERNATIVES—

Thus far we have endeavored to indicate that for a given overall machinery box length a combined space arrangement has superior permobility when compared with a fireroom/engineroom arrangement. The next logical question concerns means by which we may comparatively evaluate the merits of alternative combined space arrangements. This problem, in turn, resolves into a consideration of the number, location, and machinery content of auxiliary machinery rooms. We shall therefore consider auxiliary machinery rooms in two ways: their relation to propulsion space integrity, and their relation to ship service generator integrity. It will be remembered that the vital character of a ship's electrical power generators has already been emphasized incident to defining permobility.

First we shall consider the relation of auxiliary machinery rooms to the permobility aspects of propulsion unit spaces. Thus, on the basis of separation of propulsion spaces, the ideal number of auxiliary spaces would be three, such that an auxiliary space is interposed between each pair of propulsion spaces. Obviously, four auxiliary spaces would be illogical, since one auxiliary space would not be a separating space. At the same time, applying the concept of separation to the auxiliary machinery itself, logic compels the conclusion that a minimum of two auxiliary spaces is required, such that we wont have "all our eggs in one basket."

The concept of isolation as applied to auxiliary spaces ideally entails four spaces, such that each propulsion space has its corresponding auxiliary space. By the same token, three spaces would be better than two, in that only two main spaces would share a common auxiliary space, rather than there being two common auxiliary spaces each of which would serve two propulsion spaces.

The criteria of shortness militates against the adoption of four machinery

spaces, particularly since separation is ideally effected by only three spaces.

We therefore conclude that the number of auxiliary spaces should be not less than two nor more than three. Three spaces are best on the basis of both isolation and separation. Two spaces are best on the basis of shortness; it being manifest that cumulative floor area savings are realized as the number of compartments (and therefore separating bulkheads) is reduced. The inescapable conclusion is that superior propulsion unit permobility accrues to the arrangement utilizing three auxiliary spaces.

INTEGRITY OF THE GENERATING PLANT—

Finally, we must consider the influence of auxiliary spaces on electrical generator unit integrity. At this point we are fairly well committed to an arrangement comprising four propulsion spaces with three separating auxiliary spaces, or a total of seven machinery spaces. We have yet to establish the detailed allocation of generators among these spaces. In the interest of brevity we shall arbitrarily assume that a four shaft ship of the type under consideration has eight boilers, and we shall then assume eight generators, one corresponding to each boiler.

Now eight generators may be logically disposed among seven machinery spaces in only three ways. First of all, we may locate two generators in each of the four propulsion spaces. Such a solution is not desirable since it would tend to jeopardize the shortness of the propulsion space, which we wish to maintain at the minimum necessary to accommodate the propulsion unit. The second alternative would be to locate one generator in each space except the central auxiliary space, which latter would be alloted two generators. This arrangement offers good flexibility as regards sources of steam for generators located in the auxiliary spaces, and minimizes the concentration of generators since only one space has two generators. However, it introduces the twin problems of load unbalance and non-uniformity of arrangement, and inherently is repugnant to the basic concept of isolation. The final alternative consists in locating one generator in each of the propulsion spaces, and two generators each in the foremost and aftermost auxiliary spaces. In this arrangement the central auxiliary space would not contain a generator. This arrangement appears to offer an optimum compromise of flexibility and isolation, and the forward and after plants could be identical in all respects. It is therefore the recommended arrangement.

We are now left with the problem of effectively using the central auxiliary space. First of all, we shall assume four distilling plants in accordance with the concept of isolating which implies four complete and independent machinery plants. Two of these distilling units would be alloted to the central auxiliary space, and one each to the other auxiliary spaces. Such an arrangement is not contrary to the concept of isolation as would be the case if we were considering generators, since it is assumed that such non-vital auxiliaries as distilling units would be secured under battle conditions. Finally, it should be noted that the upper level of the central auxiliary space would be ideally disposed for accommodating the Central Control Station.

AN OPTIMUM DESIGN—

We have thus arrived at what appears to be an ideal machinery arrangement on the basis of permobility. It is realized that difficulty in following some of the reasoning may have been invited by failure to resort to basic sketches. However, sketches were intentionally avoided in order to arrive at a conclusion independent of particular cases. Should anyone feel inclined to disavow the conclusions of the foregeing analysis we can suggest a simple test. First of all, set down your favored arrangement beside the one proposed herein. Secondly, review the two arrangements, in turn, assuming consecutively one, two, and three, etc. contiguous spaces are disabled, and noting the corresponding number of propulsion units disabled in each case. Thirdly, assuming the generators in an auxiliary space can be supplied from boilers immediately forward and aft of that space, once again assume consecutively one, two, three, etc., contiguous spaces are disabled, and note the corresponding number of generators disabled in each case. If your arrangement survives this test better than the arrangement proposed herein, and does not entail an increase in overall box length, well—maybe you really have something permobility-wise. And that's the whole point of this treatise, to encourage arrangement analysis on the basis of permobility.

Of course, marine engineers must eventually make their peace with the naval architects. Thus, the most profound and compelling arguments in favor of a combined space arrangement may be completely nullified by the naval architect's contention that the length of the combined propulsion space is simply prohibitive. It is well, though, to remember that making such a statement doesn't make it so. Substantiating proof should be demanded. After all, the length of the machinery box is usually just slightly more than twenty-five percent of the length of the ship. In other words, compartmentation and subdivision do not have to be wholly accomplished within the confines of the machinery box. War experience has furthermore confirmed that the flotation capacity of ships already exceeds their permobility. As a matter of fact, during the recent war several immobilized ships were sunk by our own forces only with great difficulty, to prevent their falling to the enemy. It seems the permobility aspects of ship design have not received their just due.

CONCLUSION—

The foregoing is hardly proposed as the last word on a subject which is so manifestly complex. It represents only the opinion of one who has tried to analyze the problem objectively. It should be emphasized that the author is not so much concerned with being right as with promoting a discussion by more qualified and competent naval architects and engineers. Such discussion could through a process of synthesis ultimately result in a right solution. It is therefore earnestly hoped that this article will not only serve merely as a point of departure, but will moreover constitute a challenge calculated to stimulate constructive thinking, such that naval machinery arrangement designs will not only reflect an optimum design, but may be achieved in the future with a considerably improved economy of time, effort, and money.

TECHNICAL PROGRESS IN SHIPBUILDING DURING 1953

ACKNOWLEDGEMENT

This article appeared in the January 1954 issue of "The Shipbuilder and Marine Engine-Builder."

In spite of the fall in the number of orders placed in British yards, the industry is still keeping up its program of research work. The British Shipbuilding Research Association are continuing their activities, and details of some of the work published during the past year will be discussed in later sections of this article.

The Ship Division of the National Physical Laboratory has a full program of research in hand, and is also carrying out work for the B.S.R.A.

The demand from the industry for resistance and propulsion experiments, to be carried out by the Ship Division, has shown signs of falling-off during the year, and this is in line with the decline in inquiries for new tonnage. This has enabled tests to be commenced more rapidly. The chief items of research in the Ship Division are the ship-model comparison, the investigation of smooth turbulent frictional resistance, the velocity distribution in the boundary layer, the resistance and propulsion characteristics of standard series, and the interdependence of surface friction and wave-making resistance.

The extension of the research facilities in the Ship Division is also under consideration at the present time, and the No. 3 Tank Project has been approved. The new tank, when completed, will be 1,300ft. in length, and is expected to be finished by 1958. A large propeller tunnel will also be provided as part of the new facilities.

At King's College (Durham University), Newcastle-on-Tyne, propeller research is continuing in the cavitation tunnel, and some of this work will be discussed in detail later.

In the field of structural research, the B.S.R.A. program at Glengarnock continues. Other organizations interested in ship's structures include the Aluminum Development Association, who have programs of research being pursued in some of the University Departments of the country. Some of this work is concerned with aluminum structures generally, but there is, nevertheless, a good deal of this, which will eventually be of use to the shipbuilder, as well as to the structural engineer.

In the field of structural testing, a very considerable addition to the re-

search facilities is the large testing frame, at the Naval Scientific Research Establishment, Dunfermline, which was opened by the First Lord of the Admiralty in July last. The purpose of this testing frame is to enable experiments to be carried out on full-scale structures. The frame is of welded cellular construction, and, internally, is 69ft. by 33ft. by 39ft. The cells are 6ft. square, and each is capable of housing a jack which can exert a force of 500 tons. Eventually, equipment will be available enabling loads of up to 2,000 tons to be applied in a horizontal direction along the longitudinal axis of the frame. One end of the frame is hinged, which enables the structure for test to be put into the frame. There is a separate remote-control and recording room, which, together with the frame, is housed in a special building, 200ft. by 80ft. by 85ft. The testing of structures in this new piece of apparatus has not yet been started; and while the results of such tests must, of necessity, remain secret for a long time, there is little doubt that the facilities provided by this piece of equipment will lead to a better understanding of ships' structures, generally.

SHIP-DESIGN AND MISCELLANEOUS PROBLEMS

The United States Maritime Administration contracted, in 1951, for the construction of 35 fast corgo ships. At the time of writing, some of these ships have been delivered and are in commercial service as part of the United States merchant marine. It is of interest to note that the *Mariner*-type cargo ships very nearly constituted all the post-war dry-cargo vessels built in the United States.

Details of these ships are to be found in a paper read at the 1953 spring meeting of the American Society of Naval Architects and Marine Engineers, by Mr. Vito L. Russo and Mr. E. Kemper Sullivan. Some of the design details from this paper will be of interest. The considerations of foreign competition and national defense requirements suggested a high speed for these ships, and a commercial sea speed of 20 knots was decided upon, the design being built up on the basis of this speed.

In view of the trend towards the carriage of cargoes having high stowage rates, it was decided to allow for the carriage of cargoes stowing at about 75 cu ft. per ton, and this led to a choice of a cargo deadweight of 10,300 tons and a bale capacity of 750,000 cu ft. The bunker capacity, it was decided, should enable a cruising radius of 12,500 nautical miles. A draft of about 29ft. 9in. would give the necessary deadweight and cubic capacity and the ships were designed as shelter-deckers, as this draft could be obtained with that type of ship. Features were, however, included which would permit the weather deck being the freeboard deck. The maximum draft was, therefore, finally fixed at 31ft. 6in., and the scantlings of the ship were based on this draft. Thus, an operator could use this draft by closing the tonnage openings, if so desired.

An interesting feature of the design was the inclusion of watertight hatchways on the second deck, the covers being of metal and sealed with Neoprene gaskets round the peripheries.

A one-compartment standard of subdivision was obtained easily with seven bulkheads when the draft of the ship was 29ft. 9in. *i.e.*, when operating as an open shelter-decker.

The speed requirement of this type of ship necessitated a power of about 17,500 S.H.P. under normal conditions, with a reserve of power for national defense performances. Geared turbines, operating a single screw, were selected for propulsion.

All these different requirements led to a ship of the following dimensions: —Length B.P., 528ft. 6in.; breadth molded, 76ft. 0in.; depth molded to weather deck, 44ft. 6in.; displacement, 21,093 tons on 29ft. 10-1/16in. draft; and corresponding deadweight, 13,418 tons.

It is not possible to discuss this very interesting design in more detail in the limited space available here, but a study of the original paper should be of great value to the designers of high-speed cargo ships.

Attention has been directed to certain aspects of the economics of ship design by Mr. H. Hobart Holly and Mr. James A. Pennypacker, in another paper read before the American Society of Naval Architects and Marine Engineers. While the matters discussed by these authors apply to shipbuilding and ship operation in America, the situation is not dissimilar in other countries, and particularly in Great Britain. It is shown that, due to the high building and operating costs for ships in the United States it is more than ever essential that the economic efficiency of ships should be well studied in the design stage and possible efforts made to improve the efficiency. A great variety of topics is dealt with in this paper, and their impact on the economic efficiency is discussed. While it is not possible to refer to these in detail, it may be mentioned that such items as size and speed, turn-round, propulsion plant, auxiliary machinery, cargo-handling and accommodations are fully considered.

A most interesting type of vessel, about which there is perhaps very little literature, is the shallow-draft ship of the tunnel type. Mr. A. R. Mitchell, M.B.E., M.C., has helped to rectify this deficiency in a paper read before the Institution of Engineers and Shipbuilders in Scotland during the past year. The purpose of this type of craft is to enable very shallow-draft vessels to employ propellers of larger size than would normally be possible. By enclosing the propeller in a tunnel, it is possible, under working conditions, to have the propeller completely immersed, although, when at rest, the static water level is below the blade tips. In this way, more power can be absorbed than would be possible with an open propeller. The history of the tunnel-type ship is quite a long one, and this is traced very clearly in the paper. There are a great deal of model-experiment data given for various designs of tunnel, as well as constructional details and information for various vessels in service.

A matter which is extremely important to the efficiency of both merchant and naval ships is the repair facilities available. Not least important of the repair facilities is the dry-dock, and the review of the dry-dock position, given by Mr. E. L. Champness, M.B.E., M.Sc., in his paper to the Institution of Naval Architects in the spring of 1953, will be of extreme interest to all concerned with shipping. Mr. Champness represented the Institution of Naval Architects on the Dry-docks Committee, initiated by the Institution of Civil Engineers in 1948. The paper now referred to gives data supplied to that Committee on the present dry-dock position. Mr. Champness shows that, in the past, with the increasing breadth of ships for various technical reasons, certain dry-docks have become too narrow. This tendency, he considered, will not continue in the

future, because of new developments in ship construction, which should preclude any further increase of length/breadth ratio.

From an analysis of the proportions of a number of ships of widely differing types, both merchant and naval, a curve of dry-dock widths to a base of length of dock is drawn, and data relating to actual docks throughout the world are compared with this curve. This comparison reveals the fact that only six mercantile dry-docks in the United Kingdom lie above the curve, while there are some 50 docks abroad which are wider than the minimum suggested by this curve. This indicates that docks in this country are, in general, out of proportion with the modern trend.

Further light on the inadequacy of the available dry-dock facilities is obtained by a consideration of the sizes of the present-day large oil-tankers. It is clear that, as the size of tankers increases, the fewer are the docks which can accommodate them; and for the very largest tankers at present being built, there are only two or three docks available for their repair.

It is of interest to note that some dry-dock owners are, at the present time, helping to improve the situation by building new docks, although the construction of such docks entails a tremendous capital expenditure.

In the field of new construction methods in shipyards, attention has been focused during the year on optical marking-off. The mold loft has always been one of the most important departments of the shipyard; but, with the adoption of the optical system for marking-off plates and bars, the loft becomes unnecessary. In this new system, which is described by Ir. J. H. Krietemeijer in a paper to the Institution of Naval Architects, the mold loft is replaced by an office, in which drawings are prepared, generally, to a scale of one-tenth full size. These drawings, which are prepared on paper, can be made by the experienced man who formerly worked in the mold loft, or by the more highly skilled plater. The drawings are then photographed, thus producing negatives. By means of a projector, an image is projected on to the plate to be worked off. This requires a special projector room above the position where the plate is placed ready for working. Projection is vertically downwards on to the plate, which, of course, must be situated in a darkened space to enable the image to be seen clearly on the plate. The method is apparently finding considerable favor on the Continent, and Sweden, France, Germany, Belgium and the Netherlands may be mentioned as countries in which it has been adopted. While there may be objections to the use of a method such as this, it is undoubtedly one which is worthy of careful study by progressive shipbuilders.

All connected with the construction of ships will, at one time or another, have had to face the problem of assessing the value of the frictional force between the ways when a ship is being launched. They will, therefore, welcome the results of the British Shipbuilding Research Association on this subject, which have been made available during the year in the form of a paper read by Mr. J. Brown, B.Sc., and Mr. J. M. Ferguson before the Institution of Naval Architects. The experimental work was carried out in the yard of Messrs. John Brown & Co. (Clydebank), Ltd.

In all, four groups of tests were made. The first three series of tests, which covered pressures of from 1 ton to 3 tons per sq. ft., and way declivities of from ½in. to ¾in. per ft., were made with Tallene as the lubricant, while

the final series was made to test a mineral grease supplied by the Anglo-American Oil Co., Ltd. All the tests were made out of doors on a single standing way giving a length of run of 21ft. On this standing way was placed a sliding way (length 8ft. and breadth 1ft. 6in.). Time/distance records, measurements of initial force on the triggers and weather records were taken.

While the results of the tests showed that broad approximations could be made to the coefficient of sliding friction, the value of the frictional force at and immediately after the start of the motion still appears to be in doubt. Interesting results of the research are that coefficients of static friction, deduced from holding-force measurement, decrease with increase of both way declivity and the pressure on the ways. Correspondingly of course, the holding force itself, expressed as a percentage of the free gravitational force down the ways, increases with pressure and way declivity. This percentage appears never to be less than about 60 and can be as much as 80 or more. It would seem from the results that the trigger should, for safety, be designed to take almost the full gravitational force acting down the ways.

The ever-present problem of the protection of the hulls of ships against corrosion has been the subject of investigation through the year, and attention may be directed to two papers on that subject. The first of these was by Mr. John Lamb, O.B.E., and Mr. E. V. Mathias, and was read before the North-East Coast Institution of Engineers and Shipbuilders. The second was published recently by the American Society of Naval Architects and Marine Engineers, and was written by Mr. H. Franklin Harvey, Jr., and Mr. O. J. Streever.

The first paper deals with the problem in oil-tank ships. As is well known, the protection of the interior of cargo-oil tanks is a matter of serious concern to shipowners, while the protection of the external surface is one that is common to all classes of ships. Concerning the protection of the exterior of the hull, the two main problems involved are the removal of mill-scale before painting begins, so that there is no breakdown of the scale after painting, and, secondly, the use of an adequate painting system. It is of interest to note that the Anglo-Saxon Petroleum Co., Ltd., after many small-scale and some large-scale trials, decided to adopt flame-cleaning, as standard practice, to remove scale before painting. This is an oxy-acetylene process and, although costing between 4s. 0d. and 6s. 0d. per sq. yd., appears to be well-worthwhile from the results obtained. The paint system used after the flame-cleaning depends upon the position in the ship. Below the ballast draft, for example, five coats of aluminum-pigmented bituminous paint are employed; while for the boot-top, generally, three coats of the same paint are used as a primer, upon which two coats of an oleo-resinous paint are added. For topsides, an alkyd resin paint containing zinc chromate is adopted.

With regard to the interiors of the oil tanks, the Anglo-Saxon Petroleum Co., Ltd., have examined the many different ways in which corrosion might be reduced in their vessels, including surface coatings, chemical inhibitors and cathodic protection, and have decided that only the last-mentioned provides a practical solution of the problem. Cathodic protection can be of the expendable magnesium-electrode type, or of the non-expendable electrode type with an impressed current. The latter was rejected because of the danger of current discharge under explosive conditions. The results with the magnesium-electrode

method have been most encouraging, and a butane-carrier in which the experiment was made may be quoted as an example of its effectiveness. In a tank which was protected in this way, the corrosion, over a period of 10 months, was estimated to have been reduced by 25 per cent, when compared with the least corroded tank, and 85 per cent in comparison with the most heavily corroded tank. These results would tend to show that a solution of the problem of interior corrison in tankers is in sight, and the results of further experiments at present in progress are awaited with interest.

The second paper to which reference has been made describes work carried out, by the Newport News Shipbuilding and Dry-Dock Company, on the use of energized anodes for preventing corrosion of hulls. Generally, if a potential difference is applied across a cell formed by the hull and an anode suspended outside the ship (the water forming the electrolyte), a deposit, consisting mainly of magnesium hydroxide and calcium hydroxide, is formed on the hull. Early experiments at Newport News resulted in this heavy deposit being formed near the electrodes.

Some of the early patents for electrolytic protection had for their object the formation of this hard deposit, which was intended to prevent corrosion of the hull. Experience at Newport News has, however, led to the solution that corrosion of the hull can be prevented by the electrolytic method, without the production of this deposit on the hull. This required the careful adjustment of the flow of the current, and has led to what is called the counter electro-motive force system of hull protection. This method has been used on ships while fitting-out at Newport News since 1941, and the current required is reckoned to be about 5 or 6 milliamps per sq. ft. of area to be protected. It is of interest that this method of protection is now accepted by the Navy Department and the Maritime Administration, and by many private shipowners. It has been applied to over 50 warships of various types, up to the present time.

The energized-anode method can also be applied to the interiors of oil-tankers, as previously stated, and the present paper gives a brief account of an experiment made on a tank which could be used, as needed, for cargo oil, dry cargo or salt-water ballast. On examination, after several voyages, the tank which was processed in this way showed very great freedom from rust, but other tanks which were unprotected were quite heavily corroded.

While dealing with the problem of corrosion and, particularly, that in connection with oil-tankers, reference might be made to the success of cast-iron heating coils. This type of coil, developed by Mr. John Lamb, has proved its effectiveness in combating the heavy wastage in these parts when constructed of steel. Although somewhat heavier than their steel counterparts, cast-iron coils have such a high resistance to corrosion, by comparison, that this is a small disadvantage, and more and more tankers are being fitted with this type.

OSCILLATIONS OF SHIPS

The various motions which a ship may execute under sea-going conditions is a most important study, particularly so in warships. In this category, the aircraft-carrier is particularly important, as the oscillation of the ship affects the launching and landing of aircraft. Certain work carried out for

the Naval Aircraft Research Committee has been made public during the past year, in a paper by Mr. J. L. Bartlett, C.B.E., R.C.N.C. (retd.), to the Institution of Naval Architects. The information contained in this paper is based largely on a series of model experiments carried out in waves at the Haslar Tank. A model of a 710 ft. carrier, of 32,000 tons displacement, was tested in waves varying from 300ft. to 900ft. in the full scale, and at speeds of 15, 20, 25 and 30 knots, head-on into the waves. The waves were of two heights, *viz.*, L/40 and L/20. From the results of these experiments, it was possible to work out the movement of the flight deck.

It is interesting to note that there was no marked peak movement in either pitch or heave when there was synchronism between waves and ship, nor was there a peak of movement in waves in the ship's length. At the maximum speed obtainable in waves of approximately the length of the ship, the vertical movement of the forward end of the flight deck could be as much as 45ft., while the corresponding movement for the after end could be about 25ft. The corresponding maximum velocities were about 18ft. per second for the forward end and 10ft. per second for the after end. From the various data collected during the experiments, estimates will be found in the paper of the limiting conditions under which it is possible to operate aircraft. There is no doubt that research work of this character will give very useful information as to the manner in which these very important ships can be used most effectively.

Another paper on a somewhat similar subject, but concerned with the motion of ships in confused seas, was given in America in November last. This paper—written by Mr. Manley St. Denis and Mr. Willard J. Pierson, Jr.—is mainly concerned with the analysis of actual seas into a mathematical form. The conclusions which can be drawn from this paper are that the prediction of ship motion is not confined to the classical case where the sea is assured to be of regular form; by a process of advanced mathematical analysis, it is not only possible to analyze actual wave records, but also to predict the oscillations of a ship in seas which have no apparent regularity. To quote the final paragraph of this paper: — "The representation of the oscillatory motions of a ship in confused seas by a response spectrum based on a statistical definition of the seaway is sufficient to give a characterization of these motions of such completeness that the naval architect may obtain practical solutions to many problems in this field which he now deems important."

STRUCTURAL STRENGTH AND WELDING

Although comparatively little literature has been published on the subject of strength of ships during the past year, nevertheless, certain aspects of the problem are being pursued, and some of the results of such investigations have been made public. Not least among these problems is the brittle fracture of mild steel. This is one which has caused great concern to shipbuilders generally, as is well known, and they will no doubt welcome a very informative paper on the subject, presented to the Institute of Welding by Mr. W. G. Warren, R.C.N.C., and Mr. H. G. Vaughan. The authors recall that brittle fracture is not something new, nor is it associated with welded ships only. Because, of the peculiarities of the welded structure,

however, brittle fracture is more liable to occur. The effects of welding on the structure may be summarized as follows:—Firstly, whereas in riveted structures stresses through the thickness of the plating cannot arise due to structural attachments, the use of welding causes appreciable stress, in this direction, to be built up; secondly, stresses rise, due to the welding operation; and, finally, the weld metal itself can provide a source of failure. With regard to the last-mentioned, it appears, from experiments on welded deposits given by different types of electrodes, that the tendency for fissures to appear in the weld deposit varies greatly with the coating. It has been found that the occurrence of fissuring in weld metal is dependent on cooling rate, cleanliness of weld metal, hardness of weld metal, type of microstructure and the available hydrogen. Under certain conditions, fissured weld metal can precipitate brittle fracture in a weldment.

Another paper of interest concerns the fatigue problem in ships' structures, and was given by Mr. R. Weck, Ph.D., at the spring meetings of the Institution of Naval Architects. Results are given of experiments carried out on various structural details of ships, mainly the welded connections of rolled sections to plate. While the occurrence of fatigue failure in ships' structures may be a subject which is open to question, the data provided in this paper give the relative merits of different types of connections from this point of view. From these results, it is clear that certain features are bad, as, for example, the reinforcement of butt-welded stiffeners by means of a strap on the flanges. Also, scalloped stiffeners do not show up too well, and a most interesting result is the effect of having two holes in the outstanding flange of a continuous stiffener. While the stiffener without holes could sustain a stress range of ± 8 tons per sq. in. for about 2,000,000 reversals, the stiffener with holes failed when subjected to the same stress range at about 460,000 reversals. Despite the lower fatigue values of some of the methods of attachment used in shipbuilding, the author suggests, and probably rightly, that the economics of the problem should not be ignored. The question of a stiffener welded to plating may be cited as an example. The substitution of continuous fillet welding for staggered fillets would increase the number of cycles of stress before failure, by over 100 per cent. Nevertheless, as the cost of the continuous fillet is much more than the intermittent fillet, it would appear that the latter should be adopted, unless there was reason to suspect that the item under consideration was likely to be subjected to many stress reversals in its lifetime.

Many shipbuilders will, no doubt, be aware of the new Norske Veritas Rules for ships, and will be familiar with their manipulation. It is, however, of great interest to have an explanation of the reasoning behind such Rules, and this has been provided by Dr. Georg Vedeler, in a paper to the North-East Coast Institution of Engineers and Shipbuilders. Dr. Vedeler has dealt with the major features of the Rules, including, first of all, the problem of the general longitudinal strength of the ship and the apportioning of the correct "flange" area of the ship girder, *i.e.*, the cross-sectional area of the strength deck and the outer bottom. In longitudinally-framed ships, this area has to be divided between plating and longitudinals; and the correct division, so that the most efficient structure is obtained, is dealt with by Dr. Vedeler. The problems involved here are the thickness of plating in relation to spacing of longitudinals (in order to prevent

buckling of the plating), and the scantlings of the longitudinals (so that they do not themselves buckle under compressive loads). Other matters dealt with are bulkheads, the effective flange width in built-up girders, and bracketed connections. It will be found that many of the tables in the Norske Veritas Rules have been replaced by relatively simple formulae, and Dr. Vedeler's explanation of the origin of some of these should lead to a better understanding of the Rules.

Mr. H. J. Adams has continued his work on the application of the moment-distribution method to the transverse strength of ships. In his latest contribution to the North-East Coast Institution of Engineers and Shipbuilders, he has analyzed some of the results in his earlier work. The moment-distribution method has been applied to a tanker with no strut in the wing tank, a tanker with diagonal stiffening, and one with staggered wing and centre-tank bulkheads. Much useful information with regard to the relative results of different designs of structure is contained in this paper, and work such as this, together with the previous work of the author and others, will no doubt, in time, have the effect of evolving more efficient ship structures.

Most structural members in ships consist of rolled sections, either riveted or welded to plating, with the result that the built-up section so formed consists of a wide-flanged girder, the flange being formed by the plating. It has long been known that, due to shear lag effects, the bending stress falls-off in going from the centre of the flange to the edges, so that the plate attached to the stiffener is not fully effective. From this has arisen the idea of "effective breadth." This may be defined as the breadth of plating which, if uniformly stressed, would give the same total flange load as the actual stress distribution over the full breadth. There have been many solutions to this problem, and such names as that of Timoshenko may be mentioned in connection with it. Not least important in this field is the work of Commodore Henry A. Schade, U.S.N., and recently, he has contributed further to the literature of the subject in a paper read before the American Society of Naval Architects and Marine Engineers. The information presented therein is an extension of earlier work, and such problems as arise in connection with deckhouses, longitudinal bulkheads, decks and the bottom are considered on the basis of the effective-breadth concept.

The use of aluminum alloys in ships is still interesting shipbuilders, and a good insight into the views on this ship-construction problem in the United States of America is to be obtained from the paper read by Mr. C. V. Boykin and Mr. M. L. Sellers before the American Society of Naval Architects and Marine Engineers. Both of these authors are on the staff of the Newport News Shipbuilding and Dry-dock Company—builders who can be considered to have had the most experience, on a large scale, of the use of aluminum alloys in ships, in view of the fact that they constructed the *United States*. The data presented in this paper are mainly concerned with the practical side of construction in the lighter materials.

It is of interest to note some of the points where methods differ from those in other countries. The question of material is one important matter. Here, the Americans prefer the heat-treatable material 61S., because of its high strength compared to that of the non-heat-treatable materials, while it also has a high resistance to corrosion. Because of the good weldability of the

non-heat-treatable materials, however, it appears that some attention is being given to these alloys. The non-heat-treatable alloys have not been much used in America up to the present. The efficiencies of welded joints made in heat-treatable materials are quite low, and figures of about 60 per cent. are those to be expected, whereas 90 per cent. or over is the figure which can be obtained in the non-heat-treatable materials in common use in this country in shipbuilding.

The attitude in America in regard to the design of aluminum superstructures for ships is of interest. The basis of design appears to be to employ aluminum plate for the "longitudinal" material of the structure, while transverse rigidity is obtained by means of steel members. This means that the plating of decks and sides of superstructures is aluminum, while the deck beams and side stiffeners are steel. This again shows the difference between American and British practice. Such superstructures as have been built in this country have usually also had aluminum transverse stiffening where this material has been employed. Many other practical topics of interest will be found in this very informative paper, and the designers of ships' structures in aluminum alloy can be strongly recommended to study its contents.

An interesting piece of aluminum-alloy construction in this country is represented by the yacht *Morag Mhor*, designed by Messrs. Laurent Giles & Partners, Ltd., of Lymington, Hants., in conjunction with Messrs. Saunders-Roe (Anglesey), Ltd., for the British Aluminum Co., Ltd., of London. This auxiliary twin-engined motor yacht is 72ft. in length and the principal feature of interest is that she is of all-welded construction. The process used in her construction is the so-called self-adjusting arc process, employing American Aircomatic apparatus and the Argonaut equipment of the British Oxygen Co., Ltd., of London, and is a consumable-arc procedure, in which the arc is surrounded by an argon shield. The plate material used in the *Morag Mhor* was NP5/6—a non-heat-treatable alloy. The sections were extruded from NE.6 material. The hull was framed longitudinally, and transverse strength was obtained by means of nine transverse bulkheads, as well as by a system of framing, spaced generally about 3ft. apart. The hull plating is 3/16in. The *Morag Mhor* has the largest all-welded aluminum-alloy hull in this country at the present time. Service experience with this vessel will undoubtedly teach much in connection with the welding of aluminum alloys, and will further the welding of these materials in other types of ships' structures.

RESISTANCE AND PROPULSION

The past year has seen considerable activity in the field of resistance and propulsion, and a very large number of technical publications have been added to the literature on the subject. In the following notes, an attempt will be made to summarize the main points of interest in these papers. It is, however, of interest, first, to discuss generally the programs of research being pursued in different places. Some reference has already been made to the program of work in hand in the Ship Division of the National Physical Laboratory, which covers much of the research work being carried out in this country. With regard to America and Holland, the reader is referred to two useful papers of general interest. One is by Mr. F. H. Todd, B.Sc., Ph.D., of the David Taylor Model Basin, and the other by Professor Ir. W. P. A. van

Lammeren, Superintendent of the Netherlands Ship Model Basin at Wageningen. Some brief account of the general scope of the work outlined in these papers might be given here.

The Bureau of Ships' program of fundamental hydro-mechanical research in the United States is planned in close association with other bodies engaged in the field, such as the Office of Naval Research, the American Society of Naval Architects and Marine Engineers, the American Towing Tank Conference, and various Universities and laboratories. The work covered embraces a very wide field, and comment here will be restricted to those researches directly connected with the resistance and propulsion of ships. A great deal of work is at present in progress on the problem of frictional resistance, and, so far as model experiments are concerned, two important objectives are aimed at, *viz.*, the development of correct testing methods, and the establishment of reliable methods of extrapolating model data to give ship powers.

An important problem related to the foregoing is a study of the boundary layer round models, and considerable research has been carried out on this subject with the object of finding suitable turbulence stimulating devices for models, so as to avoid laminar flow. Again related to this problem of turbulence stimulation is the study of the pressure gradient over the area covered, so that flow and pressure-distribution measurements have been made on a number of typical ship models. The prediction of smooth-ship resistance is also being tackled from the ship end, by exploring wake distribution by means of special apparatus designed for the purpose. Other matters connected with frictional resistance which are being studied include the influence of the curvature of the surface and the effect of roughness. The various factors governing the wave resistance of ships, both in smooth and rough waters, are also being investigated. In the field of propulsion, cavitation is being studied, together in the self-propulsive scale effect.

In the Netherlands, a wide program of research is being pursued, both at the Ship Model Basin at Wageningen, and at the Naval Architecture Laboratory at Delft. This research is divided into two parts, one dealing with improvement of hull forms, propellers and rudders, and the other devoted to the correlation of tank results with trial and service data.

In the first group are included research on systematically varied hull models, and more fundamental research of a theoretical nature on the various components of resistance, *e.g.*, frictional wave-making, pressure resistance, etc. In the propeller field, work on systematic series is being pursued alongside with developments in propeller theory. Cavitation and cavitation-erosion problems are also being followed up, and various matters in connection with the combination of the propeller with the hull are being investigated.

The second category of research includes investigations of the influence of scale effect and surface rougness of the hull form, the influence of flowing and restricted waters (an important problem with regard to ships in canals) and the influence of wind and seaway. The program of research has included the construction of a 72 ft. long steel model, the *D. C. Endert, Jr.*, which is a one-sixth full-size model. A large number of tests were made on this model in the Binnenspui Canal, Ijmuiden, but, due to the relatively unfavorable weather, it was impossible to obtain the basic resistance

curve for ideal smooth weather, and, for this reason, tests were made off the Dalmatian coast.

Another research establishment which is now getting into full working order, and producing valuable results, is the Naval Architecture Research Laboratory at King's College (Durham University), Newcastle-on-Tyne. The cavitation tunnel in particular, at this establishment, is now producing useful results; and, while experiment work has been proceeding in the tunnel for some years, it was not until recently that there appeared the first publication on the research in connection therewith. This took the form of a paper to the North-East Coast Institution of Engineers and Shipbuilders, by Professor L. C. Burrill, M.Sc., Ph.D., and Mr. A. Emerson, M.Sc.

The work recorded in this paper concerns experiments on 16 in. diameter propellers—a much larger diameter than is normally used in tunnel work. This has been made possible by the large size of the working section of the tunnel, which is 40in. deep by 32in. wide. Tests have been carried out on propellers with the same total blade area, but having three, four and five blades. In addition, tests have been made on four-blade propellers having different forms of blade section. Data and curves are given for these different experiments, and these should prove of great value to designers. An interesting phenomenon which has appeared during the tests is the "singing" of model propellers in the tunnel, and it has been possible to study the flow pattern associated with singing. Such studies should go far in the elucidation of a most difficult and troublesome problem in propellers. The high degree of accuracy of the results recorded shows that the tunnel is a valuable scientific instrument, and details of further researches are awaited with interest.

The second part of the results of the experiments on the *Lucy Ashton* has been published during the year, in a paper to the Institution of Naval Architects, the authors being Mr. J. F. C. Conn, D.Sc., Mr. H. Lackenby, M.Sc., and Mr. W. P. Walker. This work, which was undertaken as part of the B.S.R.A. research program, covered the ship-model correlation for the naked-hull conditions. Models of the *Lucy Ashton*, ranging in length from 9ft. to 30ft., were tested. The translation of the model results to full-scale was effected by means of the Froude skin-friction coefficients, and by means of several other skin-friction formulae.

Comparison was made with the full-scale results for the naked-hull condition, which included two different paint surfaces and the effects of fairing the shell seams. The paper includes the experimental results from all the models tested, so that an investigator is enabled to analyze the results in any way he pleases. Only brief comment can be made here on the results of the experiments and their comparison with the full-scale tests. Generally, however, it would appear that no one of the methods for expanding model results to the ship would cover adequately all the model lengths and speeds tested. The Schoenherr line would seem to give the best results, and extrapolation on this basis indicates that a roughness allowance varying from $+0.00013$ to $+0.0003$ would require to be made to the C_f values, in order to obtain agreement with the ship. The figure of $+0.00013$ is associated with faired seams and an aluminum painted surface, while the figure of $+0.0003$ is for sharp seams and red-oxide paint. This series of experiments represents, together with the full-scale work previously published, a very comprehensive piece of research, and will repay careful study by investigators in this field.

An interesting point which emerged from the model experiments on the *Lucy Ashton* was the fact that the larger models were affected by the restriction of flow caused by the proximity to the tank boundaries This effect has come to be known as blockage, and Professor E. V. Telfer, D.Sc., Ph.D., has pursued his own ideas on this subject in a paper given to the North-East Coast Institution of Engineers and Shipbuilders. Professor Telfer states that, before results obtained from a series of geometrically similar models can be applied to a ship, they must be corrected for blockage. He has developed a method for doing this; and he claims that, when applied to the *Lucy Ashton* experiments, the derived real extrapolator agrees exactly with that previously obtained from fully turbulent planks, pontoons and pipes of the same length/girth ratio as the *Lucy Ashton*. It is suggested that, after allowance for roughness effects, there is a further residual difference between model and ship to be accounted for, and that there is either a wave-making scale effect or a ship shallow-water effect.

Reference might be made here to three studies on the problem of frictional resistance of ships—a matter which is still open to controversy, as will be apparent from a study of the literature on the subject. The first of these is an investigation by Mr. L. Landweber, entitled "The Frictional Resistance of Flat Plates in Zero-pressure Gradient," and read before the American Society of Naval Architects and Marine Engineers. The laws of the turbulent boundary layer on a smooth flat plate are reviewed and evaluated by the author, and the thickness of the layer is calculated. The sheer stresses at the wall are calculated in terms of Reynolds number, and the coefficient of total resistance is also derived in terms of Reynolds number. The results obtained by this method of analysis are compared with values obtained from boundary-layer measurements and also with those obtained from the Schoenherr formula. With regard to the latter formula, almost complete agreement is obtained by the method outlined by the author for calculating the resistance from the boundary-layer laws. Agreement is also obtained with some of the data from other sources, particularly at the higher Reynolds number, although at the lower Reynolds numbers there are some discrepencies.

The second frictional resistance study is contained in a paper by Mr. J. F. Allan, D.Sc., and Mr. R. S. Cutland, read before the North-East Coast Institution of Engineers and Shipbuilders, and concerns resistance measurements on three smooth planks 50ft., 18ft. and 10ft. in length. These experiments were carried out at the Ship Division of the National Physical Laboratory. The wake distribution round the planks was measured by means of Pitot tubes, precautions being taken to ensure turbulent flow. Resistance was calculated by the momentum drag method. The results showed that the width of the friction belt did not vary with speed, nor did it vary with draft. The depth of the wake below the keel was substantially equal to the width of the friction belt. It was found that the width of the wake belt d, at any distance l from the forward edge of the planks, could be written $d^2 + 4.0d = 0.065l$.

The velocity u in the friction belt, expressed as a fraction of the velocity U of the plank through undisturbed water, could be expressed by $\frac{u}{U} = 1.036 \left(\frac{y^n}{d}\right)$, where y is the distance from the surface and u varies with the Reynolds number at the point

in the length being considered, *i.e.*, with $\frac{Vx}{\nu}$, where x is measured from the bow.

In the second part of the paper, the authors give a method for correcting for wake scale effect between model and ship.

Finally, in this group of frictional resistance investigations, attention should be drawn to the paper presented to the Institution of Naval Architects by the Reverend R. T. Shiells, B.Sc., Science Master at Brentwood School, in Essex. The author has carried out some further model experiments on resistance; on this occasion, on wall-sided models of great draft. While retaining the assumption that wave resistance and frictional resistance are mutually independent, he has proceeded to calculate the wave resistance of the models and deduct this from the total resistance giving the skin friction. In this way, he has been enabled to produce a skin-friction line. The line which has been derived lies below the Schoenherr line, but is above that recently suggested from the work of Mr. G. Hughes, D.Sc., Ph.D. The dimensions of the models used in the experiments were :—Length, 48 in.; draft, about 15 in.; and beam, 1.5, 2.25 and 3 in., respectively, in each of the three models tested. The wetted-surface area was about 10.5 sq. ft. In view of the small sizes of the models, it was necessary to ensure turbulence stimulation, and this was achieved by means of vertical sand strips, ½ in. wide, and placed ½ in. astern of the bow.

In the field of systematic series of resistance experiments, naval architects will be interested in the new Series 60 carried out in America. For full details of this work, the reader is referred to Dr. F. H. Todd's paper on the subject, to the American Society of Naval Architects and Marine Engineers. This series has been developed because of the rather disappointing results obtained with Series 57. Methods of improving Series 57 were considered, and critical comparisons made with modern ships of acceptable performance standards. The outcome of this has been the new Series 60. The particulars of the five parent forms are as follows:—Length B.P., all 400 ft.; breadth, 53.33, 55.17, 57.14, 59.26 and 61.54 ft.; draft, 21.33, 22.09, 22.86, 23.70 and 24.59 ft.; and block coefficient, 0.60, 0.65, 0.70, 0.75 and 0.80. These all have a breadth/draft ratio of 2.5. The forms have cruiser sterns and slightly bulbous bows. The general form of the sections is U-shaped rather than V-shaped. Resistance experiments for these five forms have been carried out on 20 ft. wax models run at the David Taylor Model Basin. The results are presented in the paper and many other details of the forms are included, which will make this work of great use to the designer. It may be noted that the model results have been expanded to 400 ft. length by means of the Schoenherr line and include a roughness allowance of 0.0004 on the resistance coefficient.

The first part of a new series of research work on coasters, carried out at the Ship Division of the National Physical Laboratory, is to be found in a paper by Mr. J. Dawson, B.Sc., read before the Institution of Engineers and Shipbuilders in Scotland. The full research, when completed, will include coaster forms having length/breadth ratios of 5½, 6 and 6½. The results so far published are for forms having a length/breadth ratio of 6. For this series, three block coefficients have been tested, *viz.*, 0.65, 0.70 and 0.75; and for each block coefficient, the position of the centre of buoyancy has been varied over a range appropriate

to the fullness. For each form, tests have been made at a deep load draft of 15 ft., corresponding to a 200 ft. ship at a medium draft of 12 ft., and at two ballast drafts, one of 8.5 ft. mean on a level keel and one of 8.5 ft. mean with 5 ft. trim by the stern. Results are given in the form of (C) for a 200-ft. ship to a base of $V/\sqrt{L}$.

In a paper to the same Institution, Mr. H. Bocler has given the results of an investigation carried out in conjunction with the British Shipbuilding Research Association, on the influence of the longitudinal position of the centre of buoyancy on ship resistance. The work analyses data from various sources on this subject, and a new presentation of the position of L.C.B. for the best resistance results is given. It will be remembered that, in data such as Ayre's, L.C.B. is plotted to a base of $V/\sqrt{L}$. In this new presentation, it is plotted for both single and twin-screw ships to a base of block coefficient for speeds given by $V/\sqrt{L} = 2(1.06 - C_B)$. Additional curves are given for a lower speed $V/\sqrt{L} = 2(1.03 - C_B)$. The variation in the position of L.C.B. over the range of speeds covered by the above expressions is shown to be small.

In the propeller field, Professor L. C. Burrill and Mr. C. S. Yang, M.Sc., have made quite a comprehensive theoretical investigation of the effect of varying the pitch distribution over the radius, in a paper to the Institution of Naval Architects. It is well known that many claims have been put forward for the merits of particular ways of varying the pitch of a propeller radially. It is of interest, therefore, to record that the results of seven different pitch distributions based on vortex theory calculations show no appreciable variation in overall efficiency. This conclusion may seem somewhat surprising, and, while some may question the accuracy of vortex theory calculations, there can be no doubt that, used in the comparative way which is employed in this investigation, it gives a very true picture of the relative merits of the different pitch distributions. There are other conditions apart from overall efficiency, however, in propeller design, and variation in pitch is justified if, by so doing, cavitation and flow breakdown can be avoided or minimized.

Another contribution (in this case, on propeller manufacture) has been presented to the Institution of Naval Architects by Professor Burrill. Not very many naval architects will be concerned with this side of the propeller problem; but where the valuable data included in this paper will be useful, is in giving the propeller designer a picture of what is and what is not possible, and should guide him in choosing shapes of blade sections and pitch distribution, since it is of little value to put forward some advanced design which will give a theoretical improvement, if the propeller cannot be manufactured in accordance with the design.

Mr. W. C. S. Wigley, M.A., and Professor Sir Thomas H. Havelock, M.A., D.Sc., F.R.S., have both carried out investigations during the past year on the forces acting on submerged bodies, and these are to be found in papers to the Institution of Naval Architects. Mr. Wigley's work concerns the motion of a body in still water near a free surface, and he works out the forces and moments which are experienced by such a body. Sir Thomas Havelock's analysis deals with the case where the submerged body is moving under a free surface upon which waves are travelling. These two investigations give a good insight into the behaviour of completely submerged vessels, and will undoubtedly have practical value in the problems associated with submarines.

The design of hull appendages is a subject which does not receive a great deal of attention, and, therefore, the paper by Mr. Philip Mandel, to the American Society of Naval Architects and Marine Engineers, will be welcomed. The paper deals with struts, bossings, rudders and bilge keels, and modern theoretical and experimental hydrodynamic data are brought to bear on the problem. The allowances which should be made for appendage resistance vary very considerably from as low as 2.5 per cent. in single-screw ships to as much as 30 per cent. in small, fast, twin-screw vessels.

A paper to the same Society, read during the past year, on hydrofoil-supported craft gives a most useful up-to-date account of the various problems associated with such vessels. This, of course, is a very specialized field; but it would appear that vessels of this type would have advantages in certain cases and, within certain limitations of maximum size and minimum speed, are superior to displacement on planing craft on the basis of power and speed.

About two years ago, an extensive series of trials was undertaken for the Centre Belge de Recherches Navales, on a Victory ship, *A.P.3.*, of the Compagnie Maritime Belge. The purpose was to determine the efficiency and economy of the ship and machinery in different conditions of weather and fouling. Part of the program was to correlate service data in smooth water with tank data. A model of the ship was run at the Ship Division of the National Physical Laboratory. Many records were taken of the actual ship in different conditions of loading, fouling and weather. The results of these trials have recently been made availbale in a paper read by Professor Ir. G. Aertssen, at a joint meeting of the Institution of Naval Architects and the Institute of Marine Engineers. This very informative paper contains a wealth of information, and that these data have been made available is warmly welcomed.

TESTING OF MATERIALS FOR NAVAL SHIPBOARD SEA WATER CARRYING SYSTEMS —A REVIEW—

J. W. JENKINS, Member and Commander J. B. GUERRY, USN

THE AUTHORS

J. W. Jenkins, born at Fort Reno, Indian Territory on October 25, 1892, attended Case Institute of Technology for 3 years, transferred to and graduated from University of Wisconsin in 1917 with Degree B.S. He served during World War I as a field artillery, and (later) as a flying officer in the old Aviation Section of the Signal Corps U. S. Army. He resigned in 1919 to enter on 15 years of industrial engineering experience including consulting work involving specification, design and application of engineering materials. He joined the force of the Inspector of Naval Materials, Chicago, Illinois, in May 1934 serving as Supervisor of the South Bend, District and as Technical Assistant to the Inspector of Machinery, Beloit, Wisconsin. He joined the Bureau of Ships in July 1940 and has since served in the Metallurgical Branch of the Material Development Division, presently as Head of this Branch. He has for the past decade carried on Standardization matters for the Branch. During this period he has served as Navy Department Member of the Interdepartmental Screw-Thread Committee.

Commander John Benjamin Guerry, U. S. Navy, born January 10, 1916 in Montezuma, Georgia, attended Georgia School of Technology 1933-1935, and was graduated from the Naval Academy in 1939. He was on sea duty from 1939 through 1946 and served in Destroyers during the War. He had command of the USS IZARD (DD 589) from March 1945 to June 1946. He attended the Post graduate school at the Naval Academy 1946-1947 and Cornegie Tech 1947-1949. He received B.S. and M.S. Degrees from Carnegie Tech in Metallurgy. Upon graduation he returned to sea duty as engineering officer aboard the USS LEYTE (CV 32). He reported to the Bureau of Ships in February 1952 where he is now stationed as the Assistant for Material Development.

"Making the Ocean a Test Tube," a brochure describing their Harbor Island and Kure Beach, North Carolina sea water test stations, published by the International Nickel Company has this to say about the study of marine corrosion:

"Some of the important directions in which the ocean has been put to work are for the general study of corrosion by salt water, and salt air, and study of the effects produced by marine organisms on metals, wood and other materials.

Marine corrosion, like other kinds of

corrosion, is known to be a natural electrochemical phenomenon, the basic principles of which have been established by study and research in plants and laboratories all over the world. However, the most reliable guides to the proper selection of materials for particular purposes are always based on studies carried out under the actual conditions met in service."

CORROSION-EROSION

All known metals corrode and in the process form more or less protective films. The tenacity of such films is dependent on the inherent corrosion resistance of the metal in the particular media. Moving sea water tends to erode and remove such films formed by exposure to sea water. Its "erosiveness" generally increases with velocity and turbulence. Velocity and turbulence have been problems in Navy sea water fire and flushing piping systems, and condensers over the years. Valves, bends, takeoffs, flanges and fittings are necessary evils in these systems. They, together with mismated offsets, dents, welding icicles and the like are causes of turbulence. Corrosion erosion problems are many and often difficult of solution, particularly when the necessities of conservation threaten the availability of proven material. If we cannot have materials capable of forming tenacious protective films in sea water, the integrity of sea water carrying systems is no longer assured.

Dating from the days of Dr. D. J. McAdam Jr.'s studies of corrosion fatigue some 20 to 30 years ago, corrosion studies have been carried out at the U. S. Naval Engineering Experiment Station, Annapolis, Maryland using water from the Severn River, a brackish estuary of less than sea water salinity, biological content or corrosivity. During the middle and late 1930's the Navy Bureaus and the U. S. Naval Engineering Experiment Station joined with people from various branches of industry and from educational and research activities in the work at Kure Beach, North Carolina. The original project was located on the property of the Ethyl-Dow Chemical Corporation's Bromine Plant. Specimens were located in the channel through which ocean water was pumped to the plant. Atmospheric test racks and sea spray test racks were added about 1940.

The results of early tests in natural ocean water could not be correlated with results obtained at Annapolis. Rotating disc and jet impingement apparatus used at Annapolis were duplicated and installed at Kure Beach. Results of tests with such apparatus using sea water differed considerably with results of tests in similar apparatus using Severn River water at Annapolis. These differences appeared to increase with increased velocities of specimens in the media. These differences became more important as the need for higher pressures in fire mains with attendant higher velocities in the piping systems became apparent during the early period of World War II. During this period a considerable number of failures in sea water carrying systems occurred as the result of localized erosion attack on the downstream side of valves, fittings, branch connections as well as in these parts themselves. In most instances these falures were evidently associated with water velocities higher than normal for the materials involved. These failures resulted (before the War's end) in the Engineering Experiment Station's confirmation of the necessity for service testing of simulated ships systems under live sea water conditions.

World War II experience with sea water piping and cooling systems strongly emphasized the necessity for greatly improved performance of such systems. Particular emphasis on conservation of critical materials was part and parcel of the problem. Almost double the previous velocity was indicated.

An extensive testing program was initiated to determine suitability of materials or combinations of materials as well as design information necessary to attainment of the required performance levels of the end products—piping, valves, fittings, condensers, coolers, evaporators and the like, as well as systems to prevent fouling. The immediate objective was design information suitable for prototype and experimental ships. The ultimate objective is integration of all available information as to combinations of materials and design procedures leading to savings in critical materials and costs. The program includes studies of light alloys such as aluminum and titanium (heretofore unused in similar applications) and many copper base alloys in combination with coatings, inserts or other means of protecting against local attack.

The plan of approach is twofold: (1) Various corrosion testing apparatus and exposure conditions utilizing specimens under varying degrees of attack, velocity, air, etc., are available for preliminary or screening tests of materials. The results of such tests are carefully correlated and provide economical means of comparison of the basic performance of various materials as revealed by specimen testing. Susceptibility to erosive action, selective corrosion, contact corrosion and many other effects are thus comparatively evaluated and the materials classified and judged as to the advisability of their inclusion in simulated system testing: (2) to evaluate expected behavior of materials for service use under various conditions of velocity and system design, actual systems simulating service design and operating conditions are constructed and operated under these conditions to failure wherever practicable. Since the conditions of exposure and operation are somewhat more severe than on shipboard, the pumps and electrical equipment as well as the systems which they supply are subjected to critical evaluation.

WHY WE LOCATED AT KURE BEACH

A survey of all possible locations for such test and development work was made early in 1946 by the U. S. Naval Engineering Experiment Station at the request of the Bureau of Ships. The following were among the stipulations set forth:

(a) The facilities must provide uncontaminated live sea water of proper salinity, biological content and supply for proper corrosion and corrosion-erosion as well as fouling studies.

(b) Tide effect and continuous full submergence where required.

(c) Housing facilities sufficient to set up apparatus, equipment under test together with instrumentation, steam generators and the like all within cyclone fenced area.

(d) Ample electric power.

(e) Shoreline and distant exposure racks, cyclone fences to prevent tampering.

(f) Laboratory facilities.

(g) Experienced technical and maintenance personnel permanently located.

(h) Storm barrier such as outer island to prevent wrecking of facilities.

All of the foregoing were fulfilled by the set up at Kure Beach where in the interest of scientific research the late Dr. Willard Dow made a rent free agreement with International Nickel Company, Incorporated, for use of the pumphouse and adjacent property. In

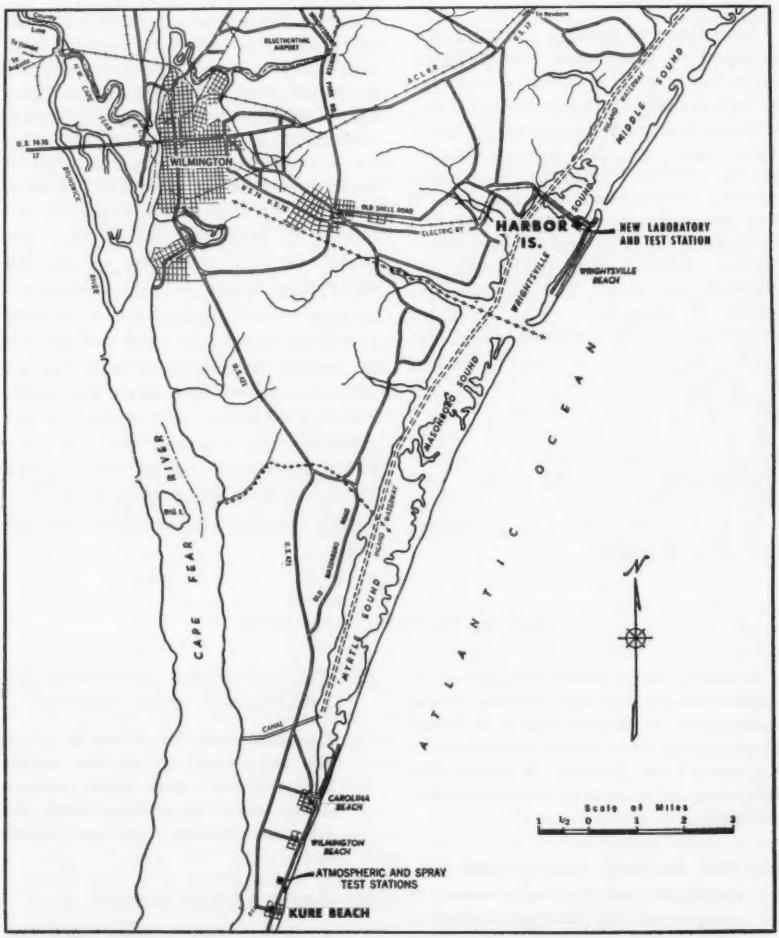

Fig. 1—Locations of the various units of the Kure Beach Project, near Wilmington, N. C.

Fig. 2—Kure Beach—The Pump House, Exposure Rocks, Old Laboratory and Ethyl-Dow Plant on the distant Cape Fear River. (1946)

1946 the Bureau of Ships awarded the first annual contract for services and facilities to International Nickel which has been renewed annually during the ensuing nine (9) years. The Government pays *only* for service of experienced personnel necessary to operate and maintain its tests and equipment, for power and fuel and necessary supplies. The Contractor has never taken a fee for his services and facilities. He has, from time to time increased his facilities to meet the needs of the Bureau's test work entirely at his own expense.

In 1950 all tests using moving water were transferred to the contractor's Harbor Island Station at Wrightsville Beach, North Carolina. Harbor Island is more favorable for the development and growth of marine organisms important in fouling studies. Specimens in both the racks 80 feet from the sea and in the distant exposure racks were left at Kure Beach. The aerial photographs and map of the general area give a good idea of the extent of the facilities and their location. (Fig. 1.)

Our part in the facility was planned to operate as a sea water testing section of the U. S. Naval Engineering Experiment Station, Annapolis, Maryland, this Station to be responsible for official reporting of results of tests.

Such reports are based on results of periodic inspections by personnel of the Engineering Experiment Station and upon records of operation and pertinent data such as speeds, temperatures, pressures, weight loss, pitting depths and the like reported as required.

Salt water piping tests at Kure Beach, North Carolina (Fig. 2) and

Fig. 3—"The Sea Horse Institute" Harbor Island Test Station, Wrightsville Beach, N. C. (1953)

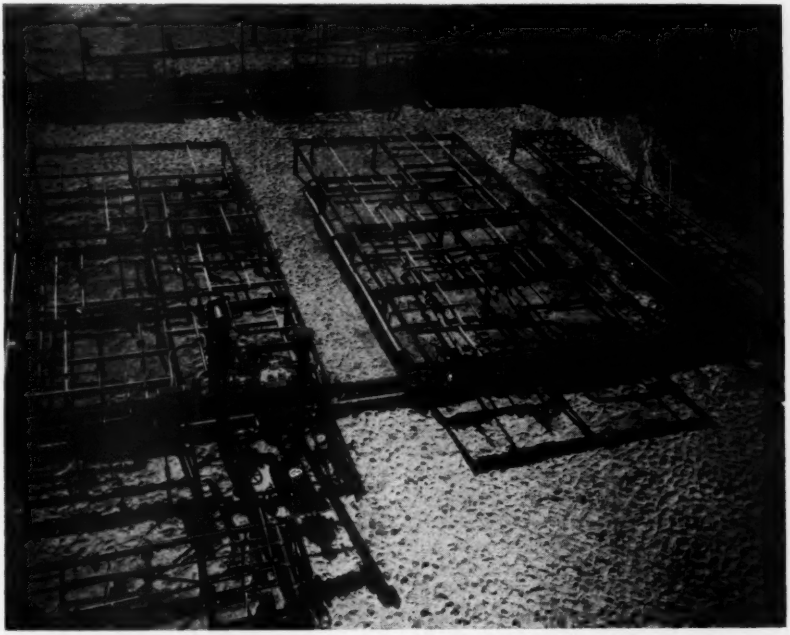

Fig. 4—Navy Piping Systems simulating Actual Service Conditions—Harbor Island Test Station

later at Wrightsville Beach, North Carolina (Fig. 3) were initiated as a result of arrangements made in connection with a Gibbs & Cox program. System No. 1 was started in February 1948. This system consisted of standard 70-30 copper nickel high iron alloy tubing. Systems No. 2 and No. 3 were started in September 1948. System No. 2 contained pipe of 70-30 copper nickel modified with aluminum. System No. 3 contained 70-30 copper nickel tubing with bronze fittings and also piping of miscellaneous alloys including 70-30 copper nickel tubing with low iron. In November 1950 the low iron 70-30 copper nickel tubing in System No. 3 was replaced with 90-10 copper nickel tubing 1¼" in diameter containing 0.87 and 1.52% iron. In September 1951 about half of the test piping in System No. 2 was replaced with 90-10 copper nickel tubing. In this latter installation both cast bronze fittings and fabricated welded fittings were used. Fig. 4 shows the general piping layouts which from time to time have included many different non-ferrous alloys as well as wrought and steel pipe systems.

SOME PAST HISTORY OF THE NAVY'S SEA WATER MATERIAL EXPERIENCE

During the early years of the century, copper was the generally approved material for salt water line. This material was far from satisfactory and efforts to find a suitable material for this service resulted about 1908 in

the development of lead lined pipe. This material, while quite heavy, was a decided improvement over copper piping from a standpoint of pitting and was specified for the fire main piping in the General Specifications for 1908, 1912 and 1917.

The Limitation of Armament Treaty in 1922 created an urgent need for weight saving and active efforts were made to find a lighter pipe material. A number of materials, such as wrought iron, brass and corrosion resisting steel were tried with little success.

As early as 1933 copper nickel came into Naval use for sea water systems. The specification permitted nickel content from 19 to 32 per cent with maximum zinc content of 6 per cent. As a result of continued tests and experience 70-30 copper nickel alloy came into being.

It was decided in 1934 to place in service for a thorough test on several destroyers, complete installation of (a) 70-30 copper nickel alloy, (b) galvanized wrought iron tubing and pipe, (c) rubber lined steel tubing with flanged composition valves, (d) copper, molybdenum bearing iron pipe, (e) galvanized steel tubing and (f) bonded lead lined steel tubing with composition valves and solder wiped composition fittings.

For various causes all were rejected after 3 years with the exception of the 70-30 copper nickel alloy. Inspection of ten ships, equipped with 70-30 copper nickel showed little or no corrosion of the tubing and pactically no fouling with marine growth. The principle troubles encountered were with the valves, cast fittings and silver soldered joints. Corrosion of valve trim was eliminated by the use of nickel copper alloy (monel) seats, stems and discs.

Several cast copper nickel alloy fittings and valve bodies failed due to porosity of the metal. Such troubles were obviated in later construction by use of Composition "M" valves fitted with monel trim and Composition "M" fittings and flanges with preinserted rings of silver solder. This combination was specified for Battleships 55 to 62, Light Cruisers 51 to 54 and for subsequent construction.

Instructions were issued to use monel when repairs are necessary to stems, seats and discs of sea water valves. This practice has endured because as of the present time, no generally available, economical alternate material has been developed and its suitability evaluated for trim of sea water valves. Later in this paper results of current tests on various materials for this purpose will be given.

Early compositions of "70-30" copper nickel alloy all provided for low iron. It was not known until the early 1940's that an iron content of about 0.50% greatly enhanced the resistance of this alloy against erosion. Ships built in the 1930's and early 1940's are equipped with low iron (0.25% max.) systems. Later instructions provide for replacement or in new construction with high iron "70-30" copper nickel. However the systems built with the low iron alloy have, with minor localized failures, shown themselves capable, with moderate maintenance, of operating during the entire life of the ship.

THE NAVY'S CONTINUED NEED FOR SEA WATER CORROSION EROSION TESTING

Not only do we float the fleet in it, but we pump sea water through extensive systems within Naval vessels. Condensers, coolers, fire and flushing services, evaporators and emergency cooling of diesel engines and similar services all use live sea water. Compensating fuel oil tanks take in ballast

sea water as the fuel is drawn off. Paints and coatings must be improved.

During World War II the demand for nickel for many applications greatly increased. This demand resulted in an all out effort to conserve this metal whenever possible. Its use was curtailed in many Naval applications and in spite of early difficulties with copper as a sea water carrying material many smaller ships were provided with copper piping as the least of several evils instead of 70-30 copper nickel alloy. Many failures occurred. The combination of circumstances resulted in renewed and vigorous effort to find a non-critical alternate for 70-30 copper nickel which might serve in another emergency. Tests were run on many new alloys and many older materials were reexamined. Of particular interest were those lower nickel, copper nickel alloys which might show good corrosion resisting properties. As early as 1945 such alloys containing 5, 10 and 15 per cent nickel with various amounts of iron were tested at Annapolis. More than ordinary resistance to corrosion erosion was indicated for a 90% copper 10% nickel with 1% iron. Systematic testing of this material was undertaken in sea water at the Harbor Island, North Carolina station in 1950. In these tests seven 90-10 copper nickel compositions with iron ranging from 0.01 to 1.95%, were compared with specimens of both low and high iron 70-30 copper nickel. Laboratory specimens were subjected to all manner of tests including high and low velocity with and without entrained air contact corrosion and stagnant water tests. Some 90-10 copper nickel pipe was installed in the piping systems. In 1951 an elaborate 90-10 copper nickel piping system and several experimental condensers were installed. Today 90-10 copper nickel with 1 to 1.5% iron has been recommended for across the board substitution for 70-30 copper nickel. The benefits and test results have been discussed in detail by Messrs. F. L. LaQue and W. C. Stewart. (1)* Either of these alloys is a satisfactory alloy for sea water piping systems and if status quo were possible considering all factors such as availability, economics, design, performance and the like, we well might forsake our efforts at Harbor Island, Kure Beach and at the U. S. Naval Engineering Experiment Station.

However, at the time of cessation of hostilities in 1945 the Bureau of Ships was well along with a very healthy reexamination of future needs and with studies of wartime performance of certain Naval Vessels. New ideas involving performance brought forth problems requiring improvements in existing metallurgical materials or development of new materials for their solution.

At the same time, this country has become increasingly aware that austerity in the use of critical alloy must be practiced. We therefore have the problem of accomplishing our objectives without the obvious solution of reaching for the optimum conventional alloy.

Assurance of suitabiity, followed by assurance of availability, is rarely a short time procedure. The longer our sojourn in this technical field, the greater our realization that we must keep our testing and development on a continuous basis and as far ahead as possible of the actual need for a given material or equipment performance level.

If the exigencies of a future emergency reduce the availability of nickel for copper nickel alloys but still allow

*Parenthized numerals refer to references at the end of this paper.

its use on a reduced basis, "90-10" copper nickel may in our opinion readily replace "70-30" copper nickel across the board saving 66⅔ per cent of the nickel necessary in an alloy suitable for the highest velocity services such as our sea water piping systems and in condensers and cooling systems of our combat ships. Work to develop a good corrosion-erosion resisting material, which is free or nearly so of critical material, should go on at the present rate. This work should include final evaluation of such material as (a) copper base alloys with various percentages of aluminum, iron, manganese and nickel, (b) aluminum alloys, (c) plastic materials.

GALVANIZED WROUGHT IRON AND BLACK STEEL PIPE

During every period of emergency in which nickel becomes a critical item the efficacy of wrought iron or steel pipe with or without galvanizing for sea water piping services injects itself again into the picture. Perhaps this is so because of lack of detailed knowledge as to severity of this service on combatant ships as compared to commercial maritime service. However its existance merits review.

Wrought iron versus steel and these materials versus inherently sea water corrosion resistant materials have inspired much discussion. Insofar as galvanized pipe is concerned we feel either material may be used about equally well. Tests at various velocities at Harbor Island, North Carolina, and vicinity showed that over an eighteen month period black wrought iron pipes closed up about twice as much from rust and marine growth as did black steel pipe. The galvanized pipes in these tests appear to point to confirmation of the findings in a paper by Mr. Paul Ffield, (2), which reports that galvanizing adds about one year to pipe life at velocities below two feet per second and that above this velocity corrosion rate increases so that at six feet per second the increase in life due to galvanizing is only about three months. Zinc is described as having moderate anti-fouling properties and, when zinc is lost, piping will foul with marine growth as well as with corrosion products.

Messrs. Slater, Kenworthy and May describe British experience (3) with these materials as follows: "Galvanized mild steel has been used in some ships for fire mains but not with much success. The zinc coating is fairly rapidly removed in fast moving sea water, after which penetration of the piping soon occurs."

Until non-hydrolizing coatings capable of resisting the erosive effects of fast moving sea water can be developed or suitable plastic pipe can be made, non-ferrous, (principally copper base and preferably, Cupro-nickel alloy) is still the answer for sea water systems.

COPPER BASE ALLOYS OTHER THAN CUPRO-NICKEL AND TITANIUM PIPING SYSTEMS

While the desirability of Cupro-nickel sea water piping and piping system parts is undeniable, the pressure of conservation has guided, (as stated above) renewed investigation of previously tested materials and a broad, open-minded investigation of new materials. Continuously cast (and drawn) Composition "M" tubing, and several aluminum bronze and alumi-

num brass compositions which have, in preliminary tests shown themselves to be fairly promising sea water alloys have been tried. In the early stage of their investigation such materials were not readily available in pipe or sheet form. To obtain such materials in form suitable for extending the tests beyond the laboratory specimen stage to simulated system testing involved considerable effort and expense.

TITANIUM

Preliminary tests of titanium specimens in sea water have placed this material very high in the list of corrosion-erosion resistant materials. In discussing titanium Mr. W. L. Williams (4) has this to say with regard to its fatigue properties in corrosive media such as Severn River water:

> "One of the most unique fatigue properties of titanium is illustrated by the corrosion-fatigue curve for Type E titanium (arc melted in copper-hot forged and annealed). The tests were made with the usual fatigue specimens by surrounding the test section with brackish Severn River water. The corrosion-fatigue curve does not exhibit an endurance limit like that in the air tests. Instead, the cyclic stress to cause failure continues to fall as the number of cycles increases. This is because corrosion is a time process. Cyclic stresses accelerate corrosion and cause the formation of very sharp corrosion pits. The sharp pits in turn accelerate fatigue by introducing stress concentrating notches.
>
> The corrosion-fatigue test is useful for comparing materials so long as the specimen size, corrosion medium, and cycle frequency remain comparable. These conditions of test have been standardized in the laboratory for a great many years; therefore some interesting comparisons can be made. It is noteworthy that heretofore two of the best structural alloys for resisting corrosion-fatigue in salt water were K-Monel and Navy Class 10 steel, the latter containing about 16 per cent chromium and 2 per cent nickel. In fact, it was this superior behavior that led to the use of these alloys for outboard shafting on PT boats. If the stress to cause failure in 50 million cycles is chosen as a basis for comparison, the materials line up about as follows:
>
> | | |
> |---|---|
> | K-Monel | 36,000 psi |
> | Class 10 steel | 36,000 psi |
> | Titanium | 60,000 psi |
>
> Titanium, then, is in a class by itself. It is the only high strength structural metal known for which the stress-cycle curve in a salt water corrosion-fatigue test approaches closely the stress-cycle curve for tests in air. Since a fatigue test is a very sensitive index of corrosion damage, the corrosion-fatigue data lend strong support to the claims of oustanding corsion resistance in marine environments."

Again, it was a long and expensive path from laboratory specimen tests to the titanium piping system now installed at Harbor Island, North Carolina for operation at water velocity of twenty (20) feet per second. During the past three years Armour Research Foundation of Illinois Institute of Technology under Navy contract developed procedures for casting titanium valve bodies. Valves were made through cooperation of Crane Company. Welded and drawn tubing was used. The system has just recently been assembled. The cost of titanium (currently of the order of $20.00 per pound) presents a barrier which can only be overcome by development of new and economical means of reduction from the ores so that the cost of titanium can reach a competitive position with materials now in current use.

TABLE II

Results of Chemical Analysis and Hardness Tests

Alloy Designation	Type of Alloy	Chemical Composition, Percent							Hardness	
		Cu	Ni	Fe	Mn	Other Elements			Rockwell Superficial 15T	Brinell Conversion 10 mm Ball 500 kg
AA	Al Bronze + Fe	90.91	0.10	2.11	-	Al-7.38			80	93
AC	70-30 Cu-Ni + 0.5 Fe	68.47	30.34 (1)	0.50	0.69				80	93
AD[2]	70-30 Cu-Ni + 0.5 Fe									
AE	70-30 Cu-Ni + 0.3 Fe	67.98	31.29 (1)	0.33	0.40				76	81
AF	70-30 Cu-Ni + 0.1 Fe	69.07	30.49 (1)	0.14	0.30				78	87
AG	90-10 Cu-Ni + 1.8 Fe	87.32	10.75 (1)	1.78	0.15				77	83
AH	90-10 Cu-Ni + 1.8 Fe	87.46	10.64 (1)	1.75	0.15				76	81
AO	Inconel	0.11	76.46 (1)	6.80	0.24	Al-0.50	Cr-15.62	Ti-0.27	86	127
AB[3]	70-30 Cu-Ni + 0.5 Fe	68.30	30.51	0.54	0.65				83	107
AB[3]	Stainless steel-Type 304	0.14	10.85	Rem.	1.67	CR-18.88	C-0.10	Si-0.81	86	127

(1) By difference.
(2) Chemical composition and hardness not determined.
(3) Duplex tube, stainless steel outside, copper-nickel alloy inside.

TABLE III

Identification and Distribution of Tubes in Experimental Condensers

Condenser No.	Condenser Tube Alloy	No. of Tubes	Wall Thickness Mils	Alloy Designation	Tube Sheet Material	Location of Tubes	Inlet Tube End
6	70-30 Cu-Ni, .03 Fe	5	49	G	70-30 Cu-Ni + 0.5 Fe	1, 4, 7, 10, 18	Flared
	70-30 Cu-Ni, .03 Fe	5	35	G		2, 11, 12, 17, 20	"
	70-30 Cu-Ni, 0.5 Fe	4	49	C		9, 14, 16, 19	"
	70-30 Cu-Ni, 0.5 Fe	5	35	C		3, 6, 8, 13, 15	"
	90-10 Cu-Ni, 2 Fe	1	35	A		5	"
7	Al 3S, Clad with 72S[1]	10	65	M	Al 2S	1, 4, 5, 7, 9, 10, 14, 16, 18, 19	Flared
	Al 3S, Clad with 72S[1]	10	49	M		2, 3, 6, 8, 11, 12, 13, 15, 17, 20	"

(1) Thickness of inside clad-layer .005" to .007".

Table III (Cont.)

Condenser No.	Condenser Tube Alloy	No. of Tubes	Wall Thickness Mils	Alloy Designation	Tube Sheet Material	Location of Tubes	Inlet Tube End
	Admiralty + As	5	49	F		1, 4, 7, 10, 18	Flared
	Admiralty + As	5	35	F		2, 11, 12, 17, 20	"
8	Aluminum Brass + As	4	49	E	Naval	9, 14, 16, 19	"
	Aluminum Brass + As	5	35	E	Brass	3, 6, 8, 13, 15	"
	Monel	1	35	T		5	Straight
	Titanium	2	35	V	70-30	2, 5	Straight
	Titanium	6	12	V	Cu-Ni +	8, 9, 12, 13, 17, 18	"
					0.5 Fe	1, 2, 4, 6, 7, 10, 11,	"
9	Hastelloy "C"	12	20	U		15, 16, 14, 19, 20	
	Stainless, Type 316	3	35	W		1, 12, 15	Straight
	Stainless, Type 316	2	28	W	Stain-	4, 9	"
	Stainless, Type 316	2	22	W	less	11, 16	"
	Stainless, Type 329	3	35	X	Type	2, 5, 20	"
10	Stainless, Type 329	2	28	X	316	6, 13	"
	Stainless, Type 329	2	22	X		14, 17	"
	Carpenter Stainless #10	3	18	Y		3, 7, 19	"
	Carpenter Stainless #20	3	18	Z		8, 10, 18	"
	"G" Bronze, Modified	3	49	B		1, 4, 10	Flared
	"G" Bronze, Modified	2	35	B		11, 17	" [2]
	Aluminum Bronze	3	49	L	90-10	14, 19, 5	"
11	Aluminum Bronze	2	35	L	Cu-Ni +	8, 15	"
	Aluminum Bronze + Fe	5	49	AA	1.35	12, 6, 16, 13, 18	"
	Aluminum Brass	3	49	E	Fe	9, 7, 2	"
	Aluminum Brass	2	35	E		3, 20	"
	90-10 Cu-Ni, 0.7 Fe	2	49	D		2, 17	Flared
	90-10 Cu-Ni, 0.7 Fe	1	35	D		1	" [3]
	90-10 Cu-Ni, 0.7 Fe	2	49	D		6, 15	" "
	90-10 Cu-Ni, 0.7 Fe	2	49	D	90-10	8, 11	Straight
12	70-30 Cu-Ni, .03 Fe	1	49	G	Cu-Ni +	5	"
	90-10 Cu-Ni, 1.7 Fe	2	49	A	1.35	9, 13	Flared [4]
	90-10 Cu-Ni, 1.7 Fe	3	49	A	Fe	4, 18, 14	"
	90-10 Cu-Ni, 1.7 Fe	2	35	A		16, 19	" [3]
	90-10 Cu-Ni, 1.7 Fe	3	49	A		20, 10, 3	" "
	90-10 Cu-Ni, 1.7 Fe	2	49	A		7, 12	Straight
	Duplex, 70-30/18-8 [5]	4	30/20	AB		1, 4, 17, 15	Straight
						6, 8, 9, 11, 13, 16, 19	"
					70-30	10, 12, 20	"
	Dual Gage, 70 30 Cu-Ni [6]	7	80-53	AC	Cu-Ni +	14, 7, 18	Flared
13	St'd. 70-30 Cu-Ni + 0.5 Fe	3	49	AD	0.5 Fe		
	St'd 70-30 Cu-Ni + 0.5 Fe	3	49	AD		2, 3, 5	" [3]
	St'd 70-30 Cu-Ni + 0.5 Fe	3	49	AD			
	Finned Tubes [7]	5	66	AE	70-30	1, 4, 5, 7, 10	Straight
	70-30 Cu-Ni + 0.3 Fe	5	58	AF	Cu-Ni +	2, 11, 12, 17, 20	"
14	70-30 Cu-Ni + 0.1 Fe	5	69	AG	0.5 Fe	9, 14, 16, 18, 19	"
	90-10 Cu-Ni + 1.8 Fe	5	58	AH		3, 6, 8, 13, 15	"
	90-10 Cu-Ni + 1.8 Fe	3	49	T		1, 8, 15	"
	Monel	4	35	T		6, 13, 18, 19	Flared
	Monel	3	49	S	Monel	2, 7, 20	"
15	A Nickel	4	35	S		3, 5, 12, 16	"
	A Nickel	6	49	AO		4, 9, 10, 11, 14, 17	"
	Inconel						

[2] Comp. "G" tube, 20 gage, in tube seat #11 split when flared. Companion tube in tube seat 17 did not split.

[3] Plastic insert cemented in inlet end of tube.

[4] Water quenched from 1700° F.

[5] Duplex tube:—Outside tube 70-30 Cu-Ni, 0.5 Fe, wall .030"; Inside tube Type 316 Stainless, wall .020".

[6] Dual gage tube— .080" wall at inlet end tapering to .054" in 30". Wall thickness of remaining 18" length— .053".

[7] All tubes in condenser #14 are of the finned type. For wall thickness variation in the finned portion, see Plate 1.

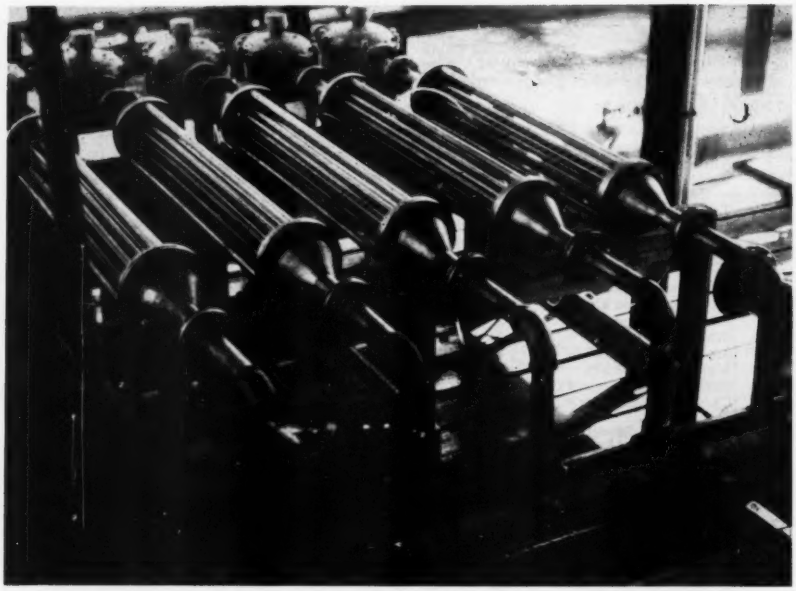

Fig. 5—Experimental Condensers at Kure Beach, N. C.
Inlet End

TABLE IV

Status of Condensers under Test in Sea Water
at 10 Ft./Sec. Water Velocity

Condenser No.	Location of Test	Installed, Date	Removed, Date	Time under Test as of May '52, Months	Status of Condenser as of May 1952
1	Kure Beach	3 Nov. '49	24 Mar. '50	4.7	One tube removed
2	"	"	"	"	All tubes removed
3	"	"	"	"	One-half of tubes removed
4	"	"	"	"	One-half of tubes removed
5	"	"	"	"	All tubes in place
6	Wrightsville Beach	5 Nov. '50	16 April '51	5.4	All tubes removed
7	"	"	Running	18	Under test
8	"	"	16 April '51	5.4	All tubes removed
9	"	"	8 Nov. '51	12	All tubes in place
10	"	"	Running	18	Under test
11	"	8 Nov. '51	"	6	Under test
12	"	16 April '51	"	12	Under test
13	"	22 Aug. '51	"	8	Under test
14	"	—	—	0	Ready for test
15	"	—	—	0	Ready for test

SEVERITY OF SERVICES

Condensers and other heat exchangers operate at water velocities of the order of 6 to 9 feet per second. Thus materials which might be suitable for coolers, condensers and like equipment (as regards water velocities and turbulence) might endanger the integrity of sea water piping systems designed to operate at from 15 to 20 feet per second and by their nature containing highly turbulent areas. For this reason extensive tests of experimental condensers and coolers have been carried on at Harbor Island Test Station. Fig. 5 shows a typical bank of five of the experimental condensers and the dock installation of test coolers.

RESULTS OF CONDENSER TESTS

Under date of 31 July 1952 the Engineering Experiment Station published an extensive and revealing report covering an important period of test of condenser tube materials. One of the principle objectives was to obtain information on alloys containing less nickel than the 70-30 copper nickel alloy generally in Naval use. Table II of the report gives chemical analyses of the various alloys.

Table III of the report contains identification and distribution of tubes in the experimental condensers and gives some idea of the extent of this investigation.

Facilities were available for testing five condensers simultaneously. From time to time, condensers were replaced with new units. Sea water was pumped through the units at a tube

TABLE V

Ratings of Condenser Tube Alloys

Alloy Type	Alloy No.	Cond. No.	Months Test	Inlet Edge Erosion	Protective Film	Relative Rating
70-30 Cu-Ni .03 Fe	G	6	5.4	Fair	Fair	III to IV
	G	12	12	Poor	Poor	
70-30 Cu-Ni 0.1 Fe + 1 Sn	K	1	4.7	Fair	Fair	III
70-30 Cu-Ni ½ Fe	C	6	5.4	Good	Good	II
70-30 Cu-Ni ½ Fe + ½ Al	I	1	4.7	Good	Good	II
70-30 Cu-Ni ½ Fe + 1½ Al	H	1	4.7	Good	Good	II
	Q	5	4.7	Good	Good	
70-30 Cu-Ni 2 Fe + 2 Mn	P	5	4.7	Good	Good	II
90-10 Cu-Ni ¾ Fe	D	3	4.7	Poor	Poor	IV
	D	12	12	Poor	Poor	
90-10 Cu-Ni 1¾ Fe	A	3	4.7	Good	Good	II
	A	12	12	Good	Good	
87 Cu-11 Ni-1½ Fe	O	4	4.7	Good	Good	II
90 Cu-6 Ni-2 Fe-2 Mn	N	4	4.7	Poor	Fair	IV
92 Cu-4 Ni-4 Al	R	2	4.7	Poor	Poor (Pitted)	V
87 Cu-10 Mn-2½ Al	J	2	4.7	Poor	Poor (Pitted)	IV
Admiralty + As	F	8	5.4	Fair	Poor	III —
Al Brass + As	E	8	5.4	Fair	Fair	III
Modfied "G" Bronze	E	11	6	Fair	Fair	III
Al Bronze	B	11	6	Fair	Fair	III +
Al Bronze + 2 Fe	L	11	6	Fair	Fair +	II —
Aluminum: 3 S Clad 72S	AA	11	6	Good	Good	II
Hastelloy "C"	M	7	18	Good	Good	I
Titanium	U	9	12	Excellent	Excellent	I
Stainless Steels, Types 316, 329, #10, #20	V	9	12	Excellent	Excellent	I
	W, X, Y, Z	10	18	Excellent	Excellent	I

velocity equivalent to 10 ft./sec. The test operated continuously except for shutdowns that were necessary for maintenance and inspection.

Table IV of the report shows status of condensers under test.

Table V of the report contains a comparative rating of the tube alloys reported therein. The ratings were based on inlet edge erosion and protective film development under the conditions of the Harbor Island experiments. The effects of tube inserts were not considered. The ratings were also based on the assumption that the tube sheets and condenser heads had no significant galvanic protective or destructive effects. Actually, only one serious case of galvanic attack was observed, i.e., the accelerated corrosion of the 70-30 copper nickel tube sheet in Condenser No. 9. Experience has indicated that the titanium and Hastelloy "C" tubes in this condenser would have provided a similar outstanding performance even if galvanic currents tending to protect the tubes had not been present.

It seems fairly certain that the gross differences between the various alloys have been revealed by the condenser tests conducted to date. However, further information of a more refined nature is warranted in some cases.

The report made the following recommendations:

"Inasmuch as condenser tubes of 90-10 copper-nickel alloy with a nominal iron content of 1.50% are provided for in Specification MIL-T-15005(SHIPS), Amendment 5 of 15 August 1951, no further recommendations with regard to condenser tubes of this alloy are deemed necessary.

Should it become necessary to consider aluminum bronze or aluminum brass condenser tubes on account of the shortage of nickel, it is recommended that favorable consideration be given to material of the type represented by alloy AA which contains about 7.5% aluminum, 2% iron, the balance copper.

It is further recommended that consideration be given to fabricating water boxes of 90-10 copper-nickel alloy as a substitute for monel water boxes that are now solder-wiped on the inside surface."

VALVES

Valves are usually areas of excessive turbulence particularly in systems using normally high velocities. Turbulence within the body is destructive both to body and to trim and the disturbance to streamline flow in the pipe system effects the pipe downstream of the valve. About one-half of the valves installed in the test piping systems are of the standard type made of Composition "M" bronze including valves with integral seats, monel seats and discs, and seats and discs of special materials which were adopted to standard valves. The remaining valves under test from time to time include special designs such as plug, gate, Y type and diaphragm valves. Compositions "M" and "G" bronzes, monel and several copper nickel alloys with from 10% to 30% nickel have been tested. The particular interest in valve tests (besides their effect on system turbulence) has been the matter of valve trim—that is—materials for stems, seats and discs.

VALVE TRIM

As previously noted nickel copper alloy (Monel) has long been recognized as the outstanding trim material for sea water valves. As a measure of economy the Bureau of Ships requires that bronze valves be suitable for low temperature steam as well as for sea water services. This requirement limits to some extent the materials that can be used particularly for stems which must be able to operate as a screw to operate the disc. Many materials gall in such applications. Monel happens to meet all requirements for both classes of valves and to require comparatively little maintenance.

Experience appears to indicate that we must take a big step away from monel to an *alternate* (not a substitute) fully as good, or, cling tenaciously to monel. Since the tonnage involved in valve trim is relatively small and the currently known substitutes give greatly reduced life in comparison with monel a change from monel at this time is considered a highly questionable conservation measure. The above considerations have influenced the trend of our investigation. Progress of the work at Harbor Island has recently been reported by the U. S. Naval Engineering Experiment Station, Annapolis, Maryland. These tests resulted from constant pressure to conserve nickel.

A brief abstract of this report follows:

Preliminary results on evaluation of materials less strategic than monel for the subject purpose, resulting from corrosion tests of laboratory specimens and actual valves tested to obtain comparative performance of stem, seat and disc materials, as well as tests to determine thread wear in steam and water indicate the following:

a. That aluminum-silicon bronze and aluminum bronze, compositions 1 and 5 of Specification MIL-B-15939(SHIPS) may prove to be fairly good stem alloys (silicon brass and certain other materials were not considered suitable for this purpose).

Sufficient data are not available at this time to recommend any particular metallic material as a substitute for monel in valve seats and discs. However, nylon can be recommended for this purpose in water valves.

On 30 August 1953 an inspection of the sea water valves at Harbor Island, North Carolina was made. A number of salt water valves, including 1-inch valves provided with special trim were examined. The valves with one exception have been under test since May 1952. The valves are contained in two lines, designated 1 and 2 for convenience of reference. During the first six months of tests the water velocity in line 1 was low for the major part of the time. In December 1952, this condition was remedied by attention to pumping capacity and the rearrangement of some of the components. The velocity in line 2 was maintained at 15 ft./sec., throughout. Valves in line 1 were kept wide open; those in line 2, two turns open or less.

The conditions of the trim for the various valves as recorded at the time of the inspection 30 August 1953, is described in Table I.

TABLE I

Condition of Valve Trim									
Line No.	Valve No.	Stem		Disc Holder		Condition of Disc		Seat	
1	7	Si Brass	P	90-10 Cu-Ni	F	90-10 Cu-Ni	F	90-10 Cu-Ni	P
1	11	Si Brass	P	None		Cu-Ni-Sn	P	Cu-Ni-Sn	P
1	9	Si Brass	P	None		Monel	G	Monel	G
1	10	Si Brass	P	None		Ni Bronze	F	Ni Bronze	F
1	8	Al-Si Bronze	E	Al-Bronze	G	Cu-Ni-Sn	F	Cu-Ni-Sn	F
1	12	Si Brass	[1]	None		Cu-Ni-Sn	G[2]	Cu-Ni-Sn	F
2	6	Si Brass	F	90-10 Cu-Ni	G	70-30 Cu-Ni		70-30 Cu-Ni	
						0.5 Fe	F	0.5 Fe	F
2	5	Si Brass	P	Al-Bronze	F	Al-Bronze	P	Al-Bronze	P
2	4	Al-Si Bronze	G	Al-Bronze	P	Nylon	E	Nylon	E
2	13[3]	Si-Brass	G	Worthite	E	Worthite	E	Worthite	E
2	2	90-10 Cu-Ni	G	90-10 Cu-Ni	F	70-30 Cu-Ni	F	70-30 Cu-Ni	F
						[4]		[4]	
2	1	Al-Bronze	G	Al-Bronze	F	Al-Bronze	P	Al-Bronze	P

[1] Not examined
[2] Gate valve
[3] Valve #13 under test since February 1953
[4] 70-30 Cu-Ni with 0.5% Fe; 1.1% Al
E—Excellent
G—Good
F—Fair
P—Poor

Four special 1-inch bronze valves obtained from the Crane Company through the Bureau of Ships were placed under test in February 1953. In these valves, the discs were secured in bronze holders by means of a flared lip. Three of the valves were tested at a velocity of 15 ft./sec. while one valve #15 was tested at 10 ft./sec. The condition of the valves as noted 30 August 1953 is given in Table II.

A 2-inch standard Navy globe valve was fitted with seat and disc of titanium made from sponge by the Brush Development Company. The

TABLE II

Part and Condition								
Valve No.	Stem		Disc Holder		Disc		Seat	
14	Titanium	E	Bronze	G[1]	Titanium	E	Nylon	E
15	Titanium	E	Bronze	G[2]	Nylon	E	Titanium	E
16	Si Brass	G	Bronze	G[2]	Nylon	E	Nylon	E
17	Titanium	E	Bronze	G[1]	Titanium	E	Monel	E

[1] The bronze lip which secures the titanium disc showed severe wastage.
[2] The bronze lip which secures the nylon disc has also eroded but to a lesser degree than denoted by note[1]. The accelerated corrosion noted for [1] is attributed to galvanic action between the dissimilar metals.

stem and disc nut were of monel metal. This valve was installed in February 1953 and was found in excellent condition in July 1953. This valve together with Valve #15 of Table II was examined especially to ascertain whether accelerated corrosion had occurred between the titanium seat and bronze body. The appearance of the parts indicated that some type of compound has been applied to the threads before assembly. Tests made during August inspection showed that compound did not result in electrical insulation between the parts. Nevertheless, there was no evidence of accelerated attack.

A 1½-inch steel globe valve fitted with a bronze disc and a steel seat overlaid with phosphor bronze was also inspected. This valve was installed in March 1952; and the seat and disc were found in good condition in July 1953. The equivalent flow through a 1½-inch pipe is 10 ft./sec. This valve is an example of a relatively large anodic area (steel) coupled with a small cathodic area (bronze); Surfaces of the latter showed a few spots where attack was rather severe. For instance, part of the female threaded portion of the body which holds the seat had corroded away.

Valve 313a, not under test at the time of the visit was exhibited. This is a standard 1¼-inch bronze valve equipped with nylon seat and disc; and was installed in December 1950. By May 1954 a hole had developed in the valve body but the seat and disc were in good condition. The valve was tested at 15 ft./sec.

The seat faces of a 3-inch standard bronze gate valve were grooved to receive ring inserts of "S" monel metal which were soft-soldered in place. The gate was fitted similarly with nylon ring inserts on either side which were cemented in place. The valve was installed in the supply line of the test system in August 1951. The valve now leaks in the closed position. Some marine growth was found in the valve and it is possible that this condition prevented the surfaces from seating. It is more difficult to secure nylon trim in gate valves than in globe valves. Other experience with this kind of modification on valves of standard design has not been happy, in that the inserts tended to swell and raise from the grooves. Recently, Walworth Company improved the basic design which was incorporated in a 6″ and two 3″ gate valves. These valves are now awaiting shipboard test.

CONCLUSIONS

The following conclusions relating to materials for valve stems seem pertinent:

a. Silicon brass is not a suitable substitute for monel metal in valve stems. Of the several alloys of this general type that were tested, aluminum-silicon bronze showed to the best advantage.

b. 90-10 Copper-nickel alloy with 1.5 per cent iron appears to be a suitable stem material for salt water valves. There is a possibility of thread seizure under conditions where stems of this material are exposed to steam as in dual service valves.

c. Ampco #8 metal is also regarded favorably for salt water valve stems. Further discrimination among the several materials will be possible after a more thorough examination of the valves on completion of the tests.

d. Monel, nylon and titanium stood out prominently as materials for

valve seats and discs. The condition of a Worthite seat and disc in one valve was excellent after about six months test. The condition of discs and seats of the 70-30 copper-nickel alloys was fair. These had been under test for about one year.

e. Test valves modified by the Station were provided with disc holders and nuts. Holders and nuts of Worthite looked the best. The condition for holders and nuts of Ampco 8 and 90-10 copper-nickel was not very different as both materials had sustained considerable erosion attack. While the nut is an interesting test application, its use in actual construction can be avoided.

In the opinion of the authors, there is much work to be done before a suitable alternate for monel can be said to have been developed.

Matters of availability, cost, and ability to design the alternates into the components will require much thought, consideration and test.

90% COPPER-10% NICKEL-1% IRON ALLOY

Earlier reference was made to satisfactory tests of 90-10 copper nickel alloy and recommendation for its substitution for 70-30 copper nickel alloy in Naval sea water piping systems. Also the adoption about 1934 of "70-30" alloy was mentioned. Some review here of fundamentals which apply to all alloys for sea water services would appear to be pertinent. During the years, there has been much speculation as to the underlying causes of corrosion-erosion encountered in salt water pipes. Heavier wall pipe to provide for effect of corrosion could not be tolerated with construction of lighter more powerful ships of the modern Navy. Sweated composition bronze fittings for use with thin walled copper nickel alloy tubing were developed.

Preliminary investigations included the determination of optimum safe water velocities for copper, 85-15 red brass and 70-30 copper-nickel alloy containing 0.25 to 0.60% iron. Other tests were made to determine the advantages of cast bronze fittings of the modified design over those of standard design for decreasing turbulence in piping systems. It soon became apparent that no major improvement could be expected from design changes in fittings, and that the inherent corrosion resistance of the pipe materials along with supplementary measures for protecting critical areas would have to be relied upon in large measure.

Service failures of salt water pipe have been examined at the Engineering Experiment Station from time to time. Examination of a considerable number of sections of 70-30 copper-nickel alloy and copper piping taken from various locations on different vessels have been made. Damage to these sections was attributed mainly to turbulence. In order to improve the situation, Navy Department Specification 44T40 for copper-nickel alloy tubing was modified to require a minimum iron content of 0.25%. Laboratory investigations had indicated that the corrosion-erosion resistance of the alloy was greatly enhanced by a small percentage of iron. Later work, including that in the early phases of the present investigation, led to further modification of the specification, and MIL-T-16420A (SHIPS) now requires an iron content of 0.4 to 0.7% for 70-30 copper-nickel.

PROTECTIVE INSERTS SLEEVES AND COATINGS

Protective inserts were installed in the pipes on the downstream side of approximately one-third of the valves and fittings contained in the three test systems. Plastic materials were used for most of the inserts, but sleeves of Hastelloy "C" were employed in a few instances. Plastic inserts of Lucite (methyl methacrylate) were installed in pipes 1½" to 3", while inserts of cellulose acetate butyrate type of resin were installed in 1¼" pipes and smaller. One insert of nylon (polymide derivative) was machined from a solid rod. Other inserts for 2" tubing were of the laminate type consisting of fibrous glass and resin.

Inserts made from plastic tubing at the Engineering Experiment Station were of two types. Those adapted for flange connections were flared at one end, this being done while the material was hot. For this design, the pipe was recessed 1/16" back in the flange and welded. This provided a seat for the flared end of the recess, which helped secure it in place. The other insert consisted of a straight sleeve tapered in the bore at both ends. This insert was adapted for use with union connections and depended on cement to hold it in place.

At the outset of the test, all plastic inserts installed in pipes at flange connections were pressed in place but not cemented. This procedure was adopted to facilitate removal of the inserts as the flare could be relied upon to hold them in place. Moreover, inserts at flange connections were installed on location. At the time of the first inspection, it was found that these inserts were in an unsatisfactory state. At the first opportunity thereafter, the inserts were sealed in with a plastic filling compound. The straight sleeve inserts were installed at the Station with Bakelite cement BC-6052 following the procedure that was developed for plastic inserts for condenser tubes. Protective sleeves of Hastelloy "C" were secured at union connections by press fit.

Several coatings were also tried as a means for protecting the pipe downstream of fittings. These included a baked ceramic coating, and a neoprene type of coating, among others. In all cases, the manufacturers applied the coating to the pipe sections.

The design of special fabricated fittings of both standard and modified copper-nickel alloys made provision for a flange at one end in order to permit entry into the lines on the downstream side.

While the value of protective inserts has been amply demonstrated in the tests, it is believed that the corrosion-erosion resistance of the standard 70-30 copper-nickel alloy is adequate except downstream of throttled globe valves. It is estimated that failures of unprotected pipe in these locations would occur in roughly six years of continuous service. Therefore, the use of inserts downstream of valves is considered desirable for maximum service life at water velocities of the order of 15 ft./sec. The type of plastic to be used for the inserts does not seem to be critical, except that the Fiberglass type is considered too rigid for general use. Both lucite and the cellulose acetate butyrate plastics have greater flexibility and are considered satisfactory. An insert is best held in a flanged joint by flaring the plastic to provide additional holding power. With a straight insert, such as used in a union joint, it is necessary to depend entirely on an adhesive to keep the insert in place.

Certain of the coatings provided good corrosion-erosion protection to pipe in turbulent areas. However, plastic inserts are considered more reliable and more adaptable for field installation.

FINDINGS

The standard 70-30 copper-nickel alloy containing a nominal 0.5% iron in accordance with Specification MIL-T-16420A (SHIPS) is considered a satisfactory material for shipboard salt water piping systems operated at water velocities up to 15 ft./sec. The most vulnerable points in such systems are immediately downstream of throttled standard globe valves.

The dissemination of knowledge among Ships' forces as to the reality of critical locations in salt water pipe lines should have a salutary effect. If operating personnel know where the natural weak links in the piping system are, they will be better prepared to cope with the situation should leaks develop. Moreover, they would be less likely to regard a few leaks as indicating that breakdown of the entire system is imminent.

The standard 90-10 copper-nickel alloy in accordance with Specification MIL-T-16420A (SHIPS) is a satisfactory alternate for 70-30 copper nickel alloy of the same specification. The resistance of the two alloys to corrosion-erosion has been similar and each alloy has shown marked superiority over low iron 70-30 copper-nickel alloy with which the Navy has had extensive experience.

Long radius elbows are preferable to short radius elbows wherever practicable. The use of fabricated fittings in lieu of cast bronze fittings would reduce weight, conserve tin, and eliminate the necessity for using combustible gases aboard ship for silver brazing. However, cast bronze fittings of the silver brazing type may give equal or longer service life. The recesses of cast fittings afford additional protection to the pipe in areas that are most likely to fail.

The piping tests have shown that areas in the pipe near the downstream side of fittings and valves are the most vulnerable to corrosion-erosion attack. It is principally because of these regions that highly resistant materials are required for salt water piping systems. Turbulence in such areas appears to correct itself and become streamline or smooth flow again within about 2 diameters of pipe length downstream of the disturbance.

In all three systems the pipe lines which carried flowing sea water were free of fouling. The absence of fouling was attributed to the relatively high water velocity rather than any anti-fouling properties of the pipe materials. Plastic pipe, which had no anti-fouling properties, was also found to be free of marine fouling under similar circumstances. Both the plastic and metallic piping systems collected colonies of mussels in the vicinity of tees that branched off to form dead ends. These growths extended only a few inches down into the dead end lines, and it was assumed that beyond this point the circulation was not sufficient to promote sea growth.

In discussing these tests the Engineering Experiment Station has commented in part as follows:

"It is apparent from the tests that the corrosion-erosion in piping systems can be controlled in large measure by attention to the following:

(a) Selection of materials having inherently good resistance to corrosion.
(b) Configuration of system including number, type and distribution of valves and fittings.

(c) Water velocity to be maintained in system.

(d) Artifices for protecting critical areas of pipe.

When the test program was initiated, one of the reasons advanced for the investigation of fabricated fittings of the copper-nickel alloys was that their use would eliminate dissimilar metals from the system. The test results do not indicate that the dissimilarity of metals as represented by copper-nickel alloy and the composition bronzes, has any important bearing on the corrosion processes encountered. The aluminum modified copper-nickel alloy tubing contained in System No. 3 was assembled with bronze fittings and the downstream pipes showed no signs of distress. Moreover, bronze is slightly anodic to copper-nickel rather than the copper-nickel tubing.

This particular investigation was undertaken to provide the best possible materials for a salt water piping system, with cost and critical nature of the alloys of secondary consideration. Emphasis in the testing of piping alloys now is focused on the conservation of critical materials. Current tests are continuing with 90-10 copper-nickel aluminum, aluminum, brass, aluminum bronze, and plastic pipes. Parts of the 70-30 copper-nickel systems are being used to distribute the water to the newer materials; hence, test experience with the 70-30 alloy will be obtained over longer periods than reported herein."

THE ECONOMICS OF 90-10 COPPER NICKEL ALLOY

Based upon prices quoted by General Stores Supply Office as of March 1953, the cost of 90-10 copper nickel tubing varies between 15% and 25% less than that for 70-30 copper nickel tubing depending upon the size of tubing involved.

The current base price for 90-10 copper nickel alloy is about 64.94 cents per pound compared to 80.02 cents per pound for 70-30. Thus there is approximately a 19% saving in the base price of 90-10 over that for 70-30.

It is roughly estimated that there is one million pounds of copper nickel tubing used in the salt water piping systems of a CVA carrier. Hence the use of 90-10 copper nickel tubing in lieu of 70-30 copper nickel tubing on such a carrier would result in a cost saving in the neighborhood of 200,000 dollars. There also would be a saving of approximately 200,000 pounds of critical nickel.

During a recent six months period approximately 806,000 pounds of copper nickel tubing were used from the Navy stocks. Converting this to annual usage, there would be an annual saving of approximately 320,000 dollars and 320,000 pounds of nickel if all issues from the supply system were 90-10 copper-nickel tubing in lieu of 70-30 tubing.

Based upon their experience in the construction of two LST's where 90-10 tubing was used for all salt water piping, the Bath Iron Works considers that it should cost no more to fabricate and install 90-10 tubing than 70-30 tubing.

PUMPS

All water for high velocity tests is moved by electric driven pumps which operate as nearly continuously as maintenance necessities will allow. In providing primary supply water to the test piping systems, condensers, coolers and the like, the pumps are operating under conditions which provide the Bureau of Ships and pump manufacturers an opportunity to study such features as deterioration of sealing rings, wear of shafts and sleeves on an accelerated basis.

Of particular interest is an endurance test recently initiated to determine the resistance to erosion of the impeller and inside of the casing, both of which have been coated with neoprene.

SEAL RINGS TESTED

A test to compare the corrosion-erosion resistance in sea water of titanium and bronze pump casing seal rings and to test the suitability of titanium for this service was run at Harbor Island. A 200 gpm, 2 stage centrifugal fire and flushing pump was used and equipped with one bronze and one titanium ring. Duration of the test was 8561 hours of pump operation. The titanium ring was in excellent condition after the test, no change in dimensions was apparent and the weight loss was insignificant. The bronze ring sustained 42% weight loss and relatively large changes in dimensions. Similar comparison test of bronze against monel showed great improvement for the monel ring.

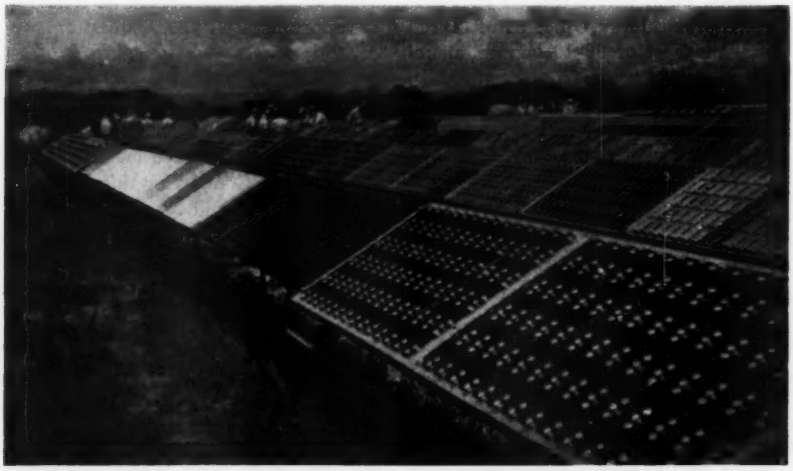

Fig. 6—General view of atmospheric test lot at Kure Beach, about 800 feet from shore

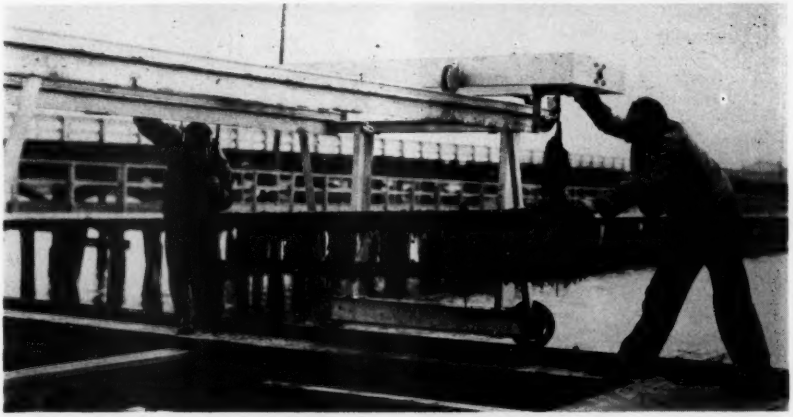

Fig. 7—A hoist lifts a rack of test specimens for preliminary inspection, before further examination of marine growth and the effects of corrosion in the laboratory. This rack also shows the extent of marine fouling by salt water.

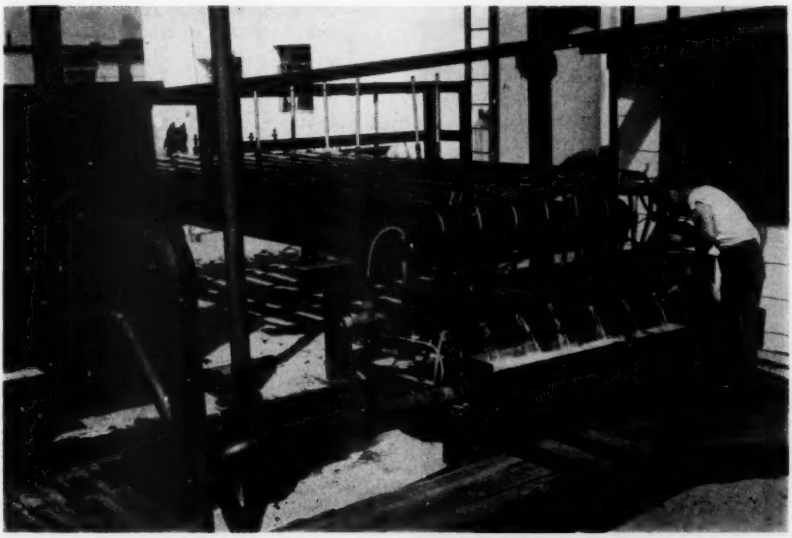

Fig. 9—Effects of the addition of chlorine, now widely used to control fouling of sea water intake lines and sliming of condenser tube surfaces by sea water are measured by this apparatus in cooperation with the William F. Clapp Laboratories, Inc., and Wallace and Tiernan.

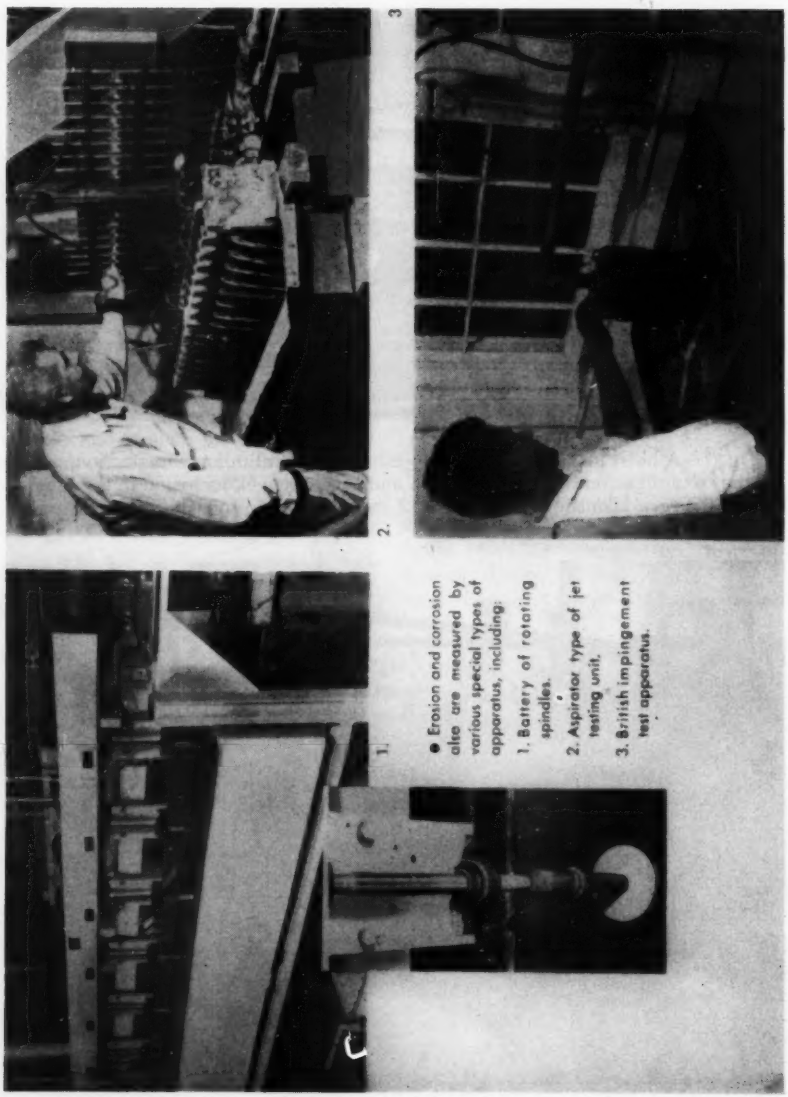
1.
2.
3
● Erosion and corrosion also are measured by various special types of apparatus, including:
1. Battery of rotating spindles.
2. Aspirator type of jet testing unit.
3. British impingement test apparatus.

Fig. 8

EXPOSURE RACKS

Racks (Figs. 6 and 7) are provided for exposure to sea atmosphere, sea spray, sea submergence, and tide effect to study hydrolysis, marine borer attack, corrosion, and fouling. For example:

In one investigation some 60 fifty-five gallon drums with various protective coating are undergoing comparative tests in the area 80 feet from the sea where they are subjected to spray and drying cycles.

Another investigation is underway to determine the performance of various combinations of primers and anti-fouling shipbottom paints. A report has been made after 22 months exposure in sea water at Harbor Island. Of the 37 systems, 8 showed no visual evidence of coating failure. These 8 systems also had high resistance to fouling by marine organisms. The remaining 29 coating systems showed varying degrees of coating failures.

Another investigation has to do with evaluation of ceramic coatings as protection against sea water corrosion.

Some 29 panels of various protective coatings including rubber and synthetic rubber in combination with coats of anti-fouling paints have been exposed for varying periods. Flame sprayed thiokol with hot plastic anti-fouling paint studied in these exposure tests appeared to be the best of the systems tested for resistance to fouling and erosion. The findings of these tests have been amply confirmed by subsequent service protection of struts and rudders.

Exposure space is provided for and occupied by textiles, plastics, wood preservative studies not to mention extensive cathodic protection devices. Each of the dock supports is an experiment in its own right.

TEST EQUIPMENT

Some twelve polarization test units, which study electrochemical characteristics of metals and alloys and which are important in predicting and explaining their galvanic behavior are available. (Fig. 8)

Navy machines for specimen testing include the following:

1 shallow tank and 1 deep tank rotating disc tester for condenser tubes

1 jet impingement apparatus—1 unit, 24 cells

1 low speed and 1 high speed rotating disc corrosion testers

2 high speed galvanic units

1-3 specimen corrosion fatigue machine.

ANTI-FOULING STUDIES

Five progress reports describing results of tests to determine the effectiveness of hot water treatment for controlling marine growth have been issued.

The work was performed by the William F. Clapp Laboratories, Duxbury, Massachusetts at Harbor Island. Early in the experiments it was indicated that fouling organisms in piping

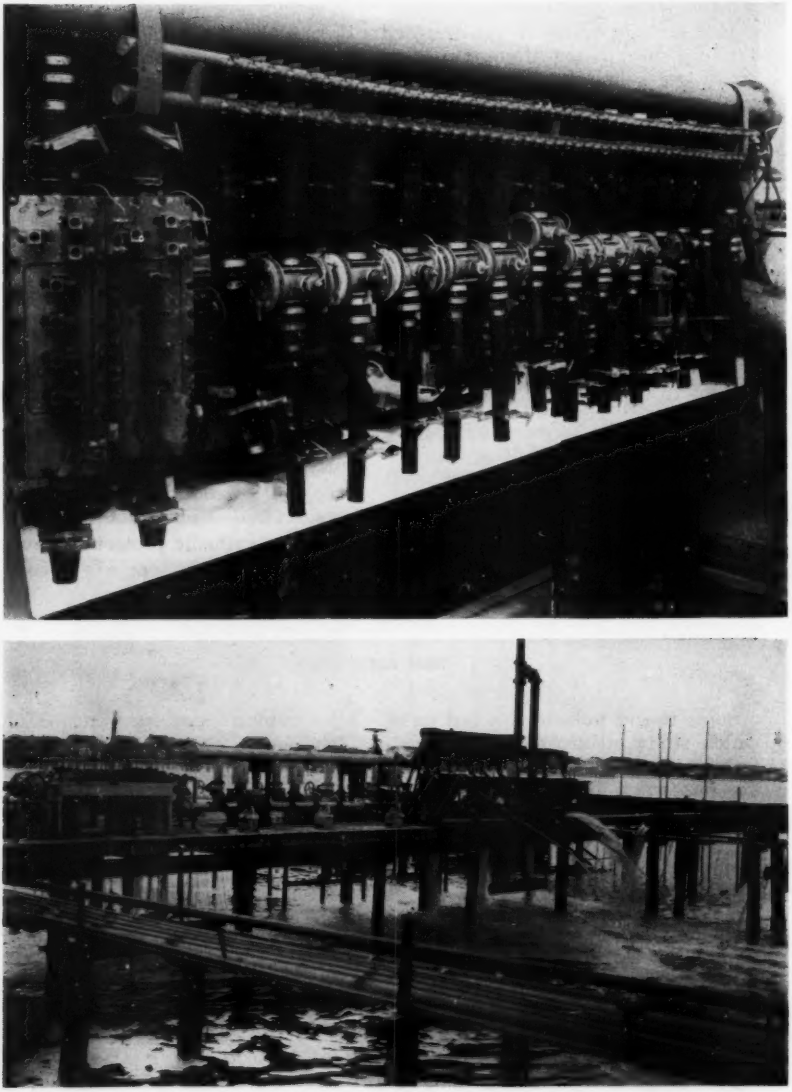

Fig. 10—Full-sized and scale model equipment also get thorough testing on the dock, among them Harrison Radiator oil and water coolers.

systems could be killed by periodic heat treatment with hot water.

Control of fouling by addition of chlorine was studied in the equipment shown in (Fig. 9). Chlorine was generated by a cell furnished by Wallace and Tiernan and injected into the water stream. The work again was performed by the William F. Clapp Laboratories. One quarter part per million continuously added or larger amounts for interrupted periods have been effective in preventing fouling.

EQUIPMENT TESTING

During the past two and one-half years operating tests have been conducted on one Griscom-Russell 8000 gallon per day 'Sola shell' double effect distilling plant, two Badger Manufacturing Company Model AAA-1 1000 gallon per day vapor compression distilling plants and one Maxim Silencer Company, double effect evaporator. Steam required is supplied from a Cleaver Brooks, Model OB-12-M 4000 pound per hour steam generator. The tests included chill shocking, acid cleaning and evaluation of water treatment equipment.

COOLERS

Full scale tests were carried out on Harrison Radiator Diviaion lubricating oil coolers to study the effect of cathodic protection of sea water borne surfaces on the corrosion-erosion resistance of these coolers and to study factors effecting their design. (Fig. 10)

WOOD, CORDAGE, PRESERVATION, METAL FASTENERS

The William F. Clapp Laboratories, Inc., have carried out several interesting and profitable activities for the Bureau of Ships at Kure Beach and Harbor Island. These have included studies on marine borer attack on both domestic and tropical woods, and on various preservative treatments and plastic overlays on plywood, cordage burial at low-high tide, tests of metal fasteners and anchor chain links. A brief outline giving some high points of this work follows. A guide to many detailed tests will be found in progress reports by the Clapp Laboratories.(5)

TROPICAL WOOD MARINE BORER TEST

In order to obtain information regarding the marine borer resistance of various native and tropical species of woods the William F. Clapp Laboratories cooperated with the Industrial Test Laboratory, Naval Shipyard, Philadelphia and Yale University School of Forestry in their program with the Bureau of Ships. As the program at Yale is primarily concerned with tropical species, the assistance and cooperation of several industrial Companies and the Forest Products Laboratory at Madison, Wisconsin were solicited and through their efforts panels of representative native species which are in constant use in marine service were provided for

tests at Kure Beach. Some 14 tropical and domestic woods were submerged in May of 1948. Many were added later. These tests revealed that the various woods have varying degrees of resistance to marine borer attack but that no known wood species is immune to this attack without preservation. Redwood and cypress heartwood panels withstood attack about 6 months at Wrightsville Beach, N. C. All other commercial domestic woods were severely riddled in 2 months exposure. Celcure, erdalith and copper naphthenate pressure treated pine panels (1.3# per cu. ft. retention) passed their third year exposure with minor damage.

About 40 or 50 species of tropical woods have been exposed for a period of 3 years. Results show that many of these species have an initial resistance to the marine borers for about two years, then quickly fail. Other studies show that Douglas fir creosote treated to a retention of about 8 to 12 lbs. and southern pine treated to about 12-16 lbs. can be painted under some conditions. Studies to determine the effectiveness of toxic preservative treatments in stopping marine borer attack after anti-fouling paint had been scraped off, showed that panels pressure treated with copper naphthenate and left unpainted were completely destroyed after three years. Panels which were originally painted and subsequently allowed to deteriorate showed considerable attack at the end of three years. Panels pressure treated with celcure and left unpainted showed no attack at the end of three years, while painted panels which are allowed to deteriorate showed slight attack at the end of three years. The preservative erdalith or greensalt, while not included in this study, was expected to give similar results to celcure. A creosote treatment to 11 pounds retention showed some attack after a two year period. The best preservative now recommended for marine borer protection is a solution of 30 per cent cold tar to 70 per cent creosote. Plastic laminates of resin bonded fiberglass and canvas laminates showed no evidence of attack by marine organisms until after four years, at which time marine fungi attack became very prevalent in the canvas laminations. These studies showed that anti-fouling paint adhesion was poor on plastic laminations.

METAL FASTENINGS CORROSION TEST

Over the years various preservatives have been investigated to evaluate their effectiveness in service as treatments for boat planking against marine borer attack. Knowledge regarding the corrosion of the various metal fasteners used in boat construction with treated planking had not kept pace with preservative development. The Clapp Laboratories without sponsorship initiated a preliminary investigation at Kure Beach to obtain correlated information relative to this problem. Fastenings were installed in each of 2″x4″x18″ blocks treated with various preservatives. Twelve (12) fasteners of each alloy shown were used and the blocks exposed after weighing carefully. The following alloys were used:

1. 304 Corrosion resisting steel screw
2. Mild steel screw
3. 316 Corrosion resisting steel screw
4. 430 Corrosion resisting steel screw
5. 17ST Aluminum nail
6. Copper nails
7. 24ST Aluminum screw
8. Everdur (silicon bronze) screw
9. Monel (nickel-copper) screw
10. Brass screw
11. Brass nails
12. 70-30 Copper nickel nails.

The wood species used included fir and southern yellow pine treated with creosote, tanalith, copper naphthenate and chemonite. Fir was also treated with zinc chloride, chromated zinc chloride and Wolman salts. Southern yellow pine was also treated with zinc chloride, chromated zinc chloride and celcure. On the basis of visual inspection after several years of exposure the following order of merit of fastenings based on average performance with all treatments was possible:

Alloy or Metal	Average rating (10 - Perfect)
316 Corrosion resisting steel	9.7
70-30 Copper nickel alloy	8.6
Monel	8.7
Copper	8.3
Everdur	7.6
304 Corrosion resisting steel	7.5
Brass (Nails)	7.5
430 Corrosion resisting steel	7.3
Brass (Screws)	6.0
Mild steel	5.0
24ST Aluminum	3.9
17ST Aluminum	3.6

This test also studied the order of corrosivity of treatments based on average behavior of all fasteners. The results of this preliminary investigation were sufficiently enlightening to enlist the Bureau of Ships in cooperation with the International Nickel Company, Inc., the American Brass Company and other industrial companies as well as several Naval Shipyards in an extended program including an attempt to simulate actual conditions of practice such as fastening different species of wood.

STUDIES OF CATHODIC PROTECTION

Corrosion of metals in sea water is an electrochemical process which may be retarded or stopped by cathodic protection. The corrosion on ships limits the applicability of materials, necessitates modifications of designs, and is a significant item of cost. Practical methods for the installations of cathodic protection is desirable to combat corrosion on these ships. Further, by proper application of an electric current it is possible to remove rust from ferrous surfaces without further damage to the metal. Removal of rust is a prerequisite to many essential operations.

This project is concerned with the mitigation of corrosion, the removal of corrosion products by electrical means, and the development of engineering service data to enable proper application to Naval Problems. The goal is to attain savings in maintenance costs, in the frequency and length of drydockings, and in the man-power involved therefor, for ships in the Active and Reserve Fleets.

Studies of cathodic protection have been carried out at Harbor Island where laboratory as well as sea water facilities are available. These tests have included galvanic anode efficiency (aluminum alloy, magnesium alloy and zinc). Long time submergence tests of coated panels under cathodic protection are continuing.

The effect of a controlled potential (referred to the saturated calomel half-cell) on certain underwater paint systems on panels for 30 months has been determined at Harbor Island Test Station. The overall conclusions reached as a result of a 40 panel test at varying potentials are as follows:

(a) At potentials of 0.75 volts and below, vinyl, hot plastic and cold plastic paints were found to be compatible

with cathodic protection. Fouling on bituminous coatings completely obscured effects of cathodic protection.

(b) At potentials between 0.75 and 0.95 volts the results were the same as in (a) except that definite blistering and breakdown occurred with cold plastic coatings.

(c) At potentials between 1.0 and 1.1 volts the results were similar to (b) except that the hot plastic coatings completely softened and blistered. The cold plastic and bituminous coatings were not included in this series.

(d) No evidence was observed that cathodic protection had any effect on the fouling characteristics of any of the anti-fouling coatings. (Toxic Cu_2O).

Zinc anode. Joint industry-Navy tests of zinc at Harbor Island is in final stages of completion. Results indicate that if iron impurity is kept 0.0014% or below the zincs will remain active throughout their service life. Zinc Specification MIL-Z-883 is in the process of revision. A new zinc anode mounting plan and instruction has been issued by the Bureau of Ships as a result of these findings.

RECAPITULATION

It would obviously be impossible to set down, in a paper of such limitations more than a sketchy outline of the operation of a facility involved in so many ramifications of the Navy program of sea water corrosion-erosion testing. Any one of the individual projects mentioned in the foregoing pages constitutes the basis for a long and detailed story. In fact the many test reports, the reviews and the design and material specifications resulting from the work at Harbor Island and Kure Beach are encyclopedic. However, the present discourse will have been in vain if it does not bring home strongly the discovery that Kure Beach and Harbor Island have brought data and knowledge of inestimable value to the Navy, or, if it should fail to bring home the absolute necessity for conducting our preliminary and simulated service testing of sea water services with natural sea water and under the actual conditions met in service.

This testing facility operates in the best tradition of cooperative effort. Here you will find the representatives of many companies whose commercial interests might well be furthered by forthright competition, banding together to fight the common enemy corrosion whose depredations annually cost the national economy an estimated $2 billion.

As a final thought the Navy has for several years been able to make an exceptionally fortunate arrangement to carry on corrosion-erosion work under optimum conditions at just about a reasonable interest rate on what such a facility might be expected to cost today.

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SHIPBUILDING AND MARINE ENGINEERING

ACKNOWLEDGMENT

This article appeared in the 5 March 1954 issue of *Engineering*.

In many ways, the outlook for British shipbuilding is disquieting, but the larger firms of shipbuilders, at least, are assured of a high output for some years yet. Supplies of steel plate have been improving steadily and, though some work was still being held up during the last quarter of 1953 because the right sizes and types of steel plate were not forthcoming, these shortages have now been largely overcome. The output in 1953 was not much higher than in 1952, as shown in the accompanying graphs and Table I, taken from the shipbuilding returns of Lloyd's Register, but Mr. J. P. L. Thomas, First Lord of the Admiralty, has said that all possible action was being taken to increase the supply of plate to the yards, so that launchings in 1954 may reach 1.5 million tons gross. This compares with the 1.3 million tons per annum achieved during the past three years, but still falls short of the full potential in the United Kingdom of 1.75 million tons. Faster and more economic construction in 1954, however, should help British shipbuilders to counter competition from foreign builders, who, largely because of their ability to give quicker delivery, have been gaining an increasing share of world business in recent years. Some of these foreign yards are heavily subsidised, whereas British builders can hope to keep their prices competitive only by raising their efficiency.

All the main shipping companies have complained during the past two or three years of the high cost of shipbuilding, and this has been one of the factors responsible for the fall in orders for new tonnage. The downward trend had already begun in 1952, when new orders booked amounted to 1.7 million tons compared with 4 million tons in 1951; but it was greatly accelerated in 1953, when they amounted to only about 500,000 tons. There is still a total of 6 million tons of new shipping on order, so that it may seem somewhat premature to worry about the future of the industry; but whereas the bigger yards, particularly those capable of building large tankers, may take up to four years to get through the work in hand, many of the smaller shipbuilders will need to book orders very soon to take the place of work nearing completion.

Even the larger shipbuilders have little security, however, for the threat

of cancellations is constantly before them; the memory of wholesale cancellations as the slump deepened in 1930 is still vivid, and already orders for 200,000 tons of shipping have been cancelled. Further cancellations are likely if costs rise and it becomes clear to shipowners that they will be required to pay considerably more for their new vessels than they had expected: the consequences may be serious, therefore, if the engineering and shipbuilding unions succeed in pressing their claims for a 15 per cent increase in wages. It is not so much the absolute level of shipbuilding costs which is important, of course, as their relation to the prospective earnings of the new ships when they go into service; and the continuing low level of freight rates, both for tanker and dry-cargo tonnage, gives shipowners no inducement to order replacements for the large volume of over-age tonnage at sea today.

LOW SHIPPING EARNINGS

The index of freights for tramp shipping (average for 1952 = 100) never exceeded 86 in 1953, and for the last six months of the year was considerably below this, falling to 71.5 in December, compared with 146.4 in January, 1952. As a result, the amount of tonnage laid up as uneconomic is increasing and the prices of second-hand vessels have fallen markedly. A Liberty-type vessel sold in the second half of 1953 fetched only £180,000, whereas similar vessels were selling for more than £600,000 at the end of 1951. Moreover, the British dry-cargo fleet has been contracting; in 1953 it amounted to 13.9 million tons gross, compared with 14.1 million tons in 1952.

Particularly disturbing is the decline in the tramp fleet, which is now only about 2.4 million tons; 400,000 tons less than in 1951 and a million tons less than in 1939. The implications for a country dependent upon the mercantile marine for its existence in war and for important earnings of foreign currency in peace are serious. It is estimated that these earnings amounted to £225 millions in 1952, and though, with the fall in freight rates, they must have fallen off considerably in 1953, shipping still remains one of the most important British export industries.

The decline in the British merchant fleet in 1953 occurred despite an increase of 7 per cent in the tonnage of shipping entering British ports. Even so, this was 5 per cent less than in the immediate pre-war years and, as the Council of the Mercantile Marine Association have reported, the present British tramp fleet, while much smaller than it was 15 years ago, may be sufficient for requirements "or ordinary peace-time trading." Its efficiency and age distribution, however, leave much to be desired; Viscount Runciman has estimated that, in the next 10 to 12 years, something like half of the British merchant fleet will disappear by old age or obsolescence, and must be renewed. This alone should ensure sufficient work for British yards for as far ahead as it is reasonable to look, and many foreign merchant fleets are in the same condition as the British.

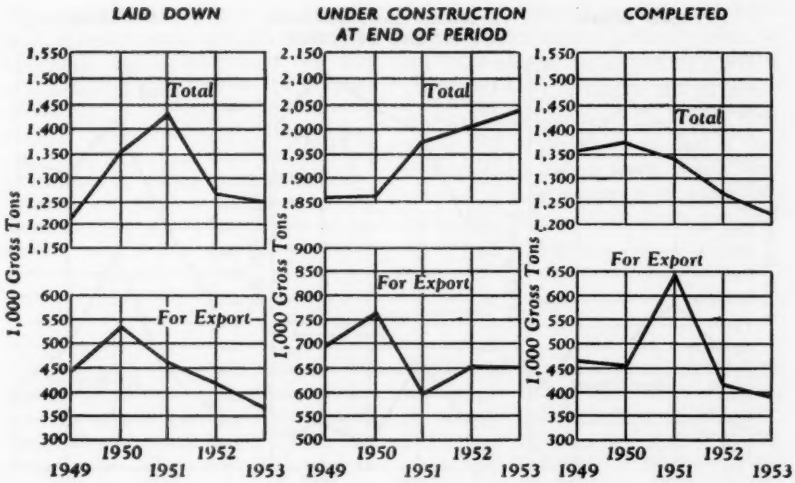
Foreign owners, however, are at present as reluctant to order new tonnage as the British. Danish shipping earnings in 1953 are expected to be £15.5 millions less than the total of £63.5 millions achieved in 1952, and, with 25 out of their fleet of 566 vessels laid up, Danish owners contracted for no new tonnage in 1953. Swedish shipping earnings in 1952 amounted to £65

millions, but in 1953 are expected to have been about one-third lower. Some Swedish owners have sold ships because they could not operate them economically. They complain that Swedish law compels them to man their ships with larger crews than, for example, the Germans.

FOREIGN FLEETS

The problem of high operating costs is even more serious for United States and Canadian owners. The British Government have agreed to a request from the Canadian Government for permission to transfer further Canadian dry-cargo tonnage to the British registry because it can no longer be worked economically without subsidy if manned by Canadian crews, whose standards of wages and working conditions are second only to those of the United States merchant marine. The latter is heavily subsidised, but, nevertheless, has suffered severely from the slump in freight rates; in January, 1953, United States vessels carried only 25.9 per cent of the foreign trade of the United States, compared with 43.6 per cent in January, 1952. Between July, 1952, and July, 1953, another 500,000 tons of shipping were added to the United States reserve fleet of laid-up vessels, mainly of the Liberty type, bringing its total to 13 million tons. A high proportion of the ships still operating were also built in war-time, and their retirement is advocated by the 15 shipping companies responsible for the publication of the bulletin, *Maritime Affairs*. In this it is stated that 83 per cent of the United States merchant fleet will have to be replaced within the next 13 years and that a program of building should be begun at once. Moreover, though no shipyard in that country was building any ocean-going passenger or dry-cargo vessels for private ownership, an additional 28 passenger or passenger-cargo liners, 430 other dry-cargo vessels and 40 oil tankers were required if United States shipping was to compete effectively.

The replacement problems of many countries are made more difficult by the continuing increase in the world fleet, which is partly due to the efforts of Germany, Japan and Italy to restore their fleets to something like the pre-war tonnage. The total world dry-cargo tonnage, excluding the United States reserve fleet, increased by nearly 700,000 tons in 1953, bringing it up to 58.4 million tons. The Italians, who have now brought their fleet back to the pre-war total of 3.5 million tons, have announced their intention to add a further 500,000 tons in the next two years. The Japanese fleet still totals only 2.3 million tons, compared with 6.3 millions before the war, but it is proposed to increase it to 4 million tons within the next four or five years. The German merchant fleet, at 1.8 million tons, is 2.7 million tons smaller than before the war, but the German Government have repeatedly affirmed their intention to bring it up to 3.5 million tons. Since comparable expansions in the world sea-borne trade are unlikely, the effect of all these building programs must be to depress freight rates further, and may mean the withdrawal without replacement of older vessels under the British flag or on the registers of foreign owners who have been accustomed to look to British yards for their replacements.

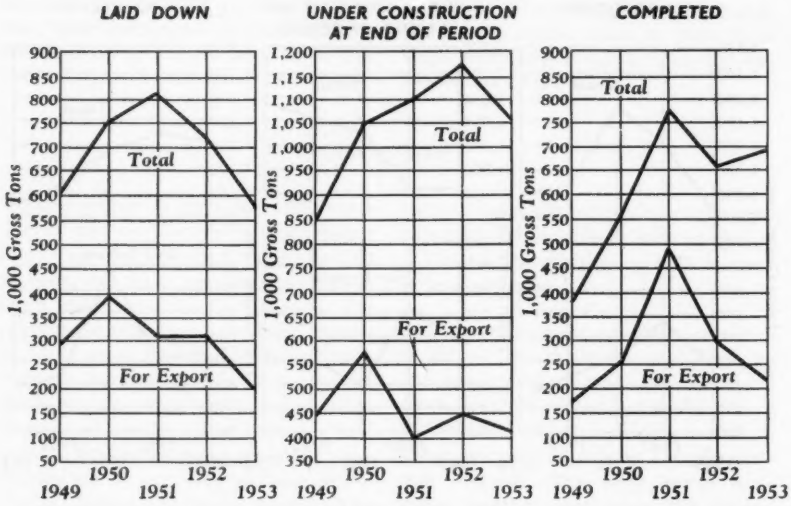


Merchant shipbuilding in the United Kingdom: the data relate to vessels of 100 gross tons and over. Output, hitherto restricted by the steel shortage, may rise considerably in 1954, but as fewer orders are now being placed, the outlook for subsequent years is not promising.

INADEQUATE DEPRECIATION ALLOWANCES

Government action could do much towards maintaining the size and efficiency of the British merchant fleet. Subsidies are not required, though, in view of the assistance given to air transport, shipowners may feel a little aggrieved. First-class passenger bookings on the world sea routes have been seriously affected by competition from the airlines, and Sir Donald Anderson, president of the United Kingdom Chamber of Shipping, said recently that "either some form of equilibrium must be established between air and sea to allow each to do what it is economically fitted to do; or sea will have to be subsidised, or air transport will simply wipe us out." Some shipping companies are tackling the problem by acquiring interests in private airlines, but this cannot be a satisfactory solution for the industry as a whole.

Subsidies apart, the most valuable assistance that the Government could render shipping would be to review depreciation allowances. Few other industries have to replace such expensive assets so frequently as the shipping industry must do, and the difference between the prime cost of ships, upon which the Inland Revenue base depreciation allowances, and their replacement costs is now considerable. Lord Teynham, in the debate on shipping in the House of Lords on December 9, said that the replacement of a ship which cost £100,000 before the war would now cost £400,000; and whereas the owner would have been prudent if he retained the £100,000 which the Inland Revenue allowed him tax-free out of profits for replacement, the remaining £300,000 would have to be found out of taxed profits. This



Tanker construction in the United Kingdom: the data relate to vessels of 1,600 gross tons and over. Output in 1954 may be a record but the declining trends indicated in the second and third graphs show that the tanker boom is over.

meant, in fact, that he would have to find more than double the amount, a total of £700,000 out of earnings, which was almost impossible.

The Government does not seem, however, to be impressed by the urgency of the situation; the Earl of Selkirk said on their behalf that they recognized the need for further action if the position was to be improved, but the question of replacement should not arise for the next five years. The shipbuilding yards were full, and the only limitations were material rather than financial. Moreover, the industry as a whole had sufficient reserves to finance the immediate program, though individual companies might be less well off.

Disappointed shipowners have not been slow to point out the dangers of this Government policy, which apparently requires that nothing shall be done until the industry is actually "on the rocks." Meanwhile, replacement costs continue to rise. The liner Orsova, launched by Vickers-Armstrongs Limited at Barrow in May, is estimated to have cost £2 millions more than her near-sister ship the Orcades, built in 1949 at a cost of about £3.5 millions. Sir John Boyd, the permanent vice-president of the Shipbuilders' Employers Federation, said in evidence before the Court of Inquiry into the industry's wage dispute, that the claim for a 15 per cent increase would add £10 millions to the wages bill, which in 1952 amounted to £57 millions. This would mean that the price of a fairly fast Diesel-engined tanker, at present just over £ 1 million, would be raised by 10 per cent.

Mr. E. J. Hill, the shipbuilders' chairman of the Confederation of Shipbuilding and Engineering Unions, countered this by declaring that profits would rise in 1954 and would be even

higher in 1955. In the past six years, he said, several companies had each paid dividends aggregating over 100 per cent and they now had capital and reserves up to six times the ordinary capital. They could not go on amassing these "colossal figures and get away with it." Since most of the shipbuilding companies are of very old foundation, it would be surprising indeed if, after two wars and attendant inflations, nominal capital still bore any relation to the present value of the real capital employed. Mr. Hill's argument that productivity in shipbuilding has increased by 33 per cent since 1948 is perhaps sounder; it was not disputed by Sir John Boyd, who attributed it to greater mechanization, which had reduced the efforts required by the workpeople.

RAISING PRODUCTIVITY

The progress of productivity in the past few years has been very much dependent upon the availability of steel. There should, therefore, be a further considerable advance in 1954, and all that can be done in this direction is necessary to meet the threat of foreign competition. Some Continental yards have been working two or three shifts a day, which both reduces their costs and enables them to give faster delivery. The seriousness of the situation is particularly apparent in ship-repairing; German ship-repairers have been attracting business from Britain by low prices, and other Continental yards have won contracts through their ability to execute work, on occasion, in not much more than half the time required by British repair yards. British ship-repairers have undertaken very heavy outlays in recent years on docks and equipment capable of handling the larger and faster vessels which are now being built, but much remains to be done. While taxation continues at the present levels, and adherence to the 44-hour weeks does not permit new equipment to be used as intensively as it might be, the incentive to modernize further is not great.

There is still, however, considerable enterprise in British shipbuilding and ship-repairing. The first stage of the first new shipyard to be laid down in the United Kingdom for 26 years was opened at Newport, Monmouthshire, at the end of November. This comprises a dry dock capable of handling vessels up to 8,000 tons and associated production sheds: it is owned by the newly-formed Atlantic Shipbuilding Company, Limited, who have stated that the second phase of their construction program, which includes a dry dock to take vessels up to 45,000 tons, will be completed in the course of 1954. A third dry dock will be added eventually, but the date of completion is still uncertain.

The plan to build vessels in dry docks has been claimed to be an innovation in British practice, though in fact this is not so; Laird Brothers, Limited, at Birkenhead—now Cammell Laird and Company (Shipbuilders and Engineers), Limited—between 1869 and 1901 built nearly a score of large ships in dry dock, under cover, including six British battleships and a liner for the Hamburg-American Line. The advantages of the method are considerable. The saving in time resulting from assembling one vessel in dry dock while the next is being made ready in sub-assembly shops should be appreciable; moreover, costs are reduced by the elimination of slip-way launchings, which require a heavy outlay on timber, etc. The company had

received orders some months before the construction of the yard was begun, and two twin-screw pulp carriers of 2,975 tons deadweight for the Quebec Ontario Transportation Company are due for delivery in August or September. Mr. John G. Howard, chairman of the Atlantic Shipbuilding Company, said in November that the company were being pressed to accept further orders for larger vessels from overseas buyers, so completion of the works could not be delayed.

FEWER TANKERS ON ORDER

Shipbuilding prosperity in the past few years has been founded upon the large orders received for tankers. The world tanker fleet now amounts to 22 million tons gross, or about 36 million tons deadweight, an increase of 16 per cent since December, 1951, and 3.6 million tons more than in December, 1952. The rate of expansion will be further increased in 1954, when nearly 4.3 million tons deadweight are scheduled for delivery. Thereafter, deliveries will fall off to 3.3 million tons in 1955 and 2 million tons in 1956, but altogether nearly 11.54 million tons are due for completion by 1957.

Meanwhile, tanker freight rates have been very weak, and there is a danger that such a large expansion may result in much unused capacity in the world tanker fleet. The spot market rate for London tanker freights, which reached a peak of 154*s.* 3*d.* per ton in January, 1952, had fallen to 29*s.* 6*d.* by the autumn of 1953, and, though there has been some subsequent recovery, they are still only about 32*s.* 6 *d* per ton. The decision of the Anglo-Iranian Oil Company and Shell Tankers, Limited, not to make use of the Brokers Award system which has been used to impart some stability to the widely fluctuating rate structure in the past few years, appears to indicate that the oil companies expect the present low level of rates to continue. Nevertheless, the volume of international trade in oil has continued to expand; in 1952, the world consumption rose by 5 per cent and the volume of crude oil entering world trade, by 1 per cent. In 1953, world crude oil production rose by over 30 million tons (about the same as in 1952) to a record of 654 million tons. The quantity entering into world trade, moreover, must have increased more than proportionately.

If freight rates have weakened despite increases of this sort, the outlook in 1954, should the present recession of 10 per cent in economic activity in the United States continue, is not bright. Moreover, if the Abadan refinery were to resume operations, there would be a significant shortening of supply lines, and a consequent fall in the demand for tanker tonnage. The demand for oil may increase in the later 1950's as the amount of new tanker tonnage coming off the stocks declines, and there is every chance that equilibrium will be reached by the early 1960's. Much will depend, of course, on the rate at which the older tanker tonnage is retired, but meanwhile the independent owners have little inducement to order new tonnage.

LARGE TANKERS

Some, however, appear to have sufficient faith in the future to order new ships. At the launch, from Vickers-Armstrongs yard at Walker-on-Tyne, on February 16, of the World Harmony, of 33,000 tons—the largest tanker yet to be built in the United Kingdom—Mr. Stavros Niarchos, who now

operates a fleet of over a million tons, said that he was negotiating with Vickers-Armstrongs Limited for further orders, which, subject to the firm being able to quote competitive prices, should reach a successful conclusion. Mr. Niarchos has already placed orders totalling £13 millions with Vickers-Armstrongs. These included two tankers, under construction at Barrow, which exceed "by a fair margin" the size of the 45,000-ton World Glory, launched by the Bethlehem Steel Company at Quincy, Massachusetts, at the beginning of February. Another Greek owner, Mr. A. S. Onassis, has some 45,000-ton tankers on order from German and French yards; the Tina Onassis, launched by Howaldtswerke of Hamburg in 1953, is of 45,720 tons deadweight, but even so was just beaten in size by the Phoenix, launched for National Bulk Carriers Incorporated at Kure, and having a deadweight tonnage of 45,800.

Apart from the oil companies themstlves, British shipowners have shown relatively little interest in large modern tankers. Mr. J. W. Platt, the chairman of Shell Tankers, Limited, speaking at the launch of the Hadra by Smith's Dock Company, Limited, South Bank-on-Tees, on November 20, said that British independent owners now had only 10 per cent of all the independently owned tanker tonnage in the world, and that the Shell Group had on charter about 4 million tons deadweight, of which 3.25 million tons were of non-British registry. This was a measure of the opportunities that had been open to British owners "in a very sound business." The latter are scarcely to be blamed, however, if they follow a cautious course while the present uncertainty about the future trend of freight rates persists. Orders for 10,000-ton tankers may be received from Russia, but these will require an export license, which may be refused. The keenness of the Russians to purchase is not in doubt, for they are said to have expressed willingness to extend the delivery dates beyond the three-years period on which they are insisting for other goods. An order already placed with British shipbuilders for trawlers amounts to £16 millions.

SUBSIDIZED FOREIGN BUILDING

The peak of the tanker boom has now been reached. As may be seen from Table II, taken from Lloyd's Register's *Shipbuilding Returns*, tankers accounted for 62 per cent of British launchings in the last quarter of 1953, but only 57 per cent of the tonnage preparing. In 1952, they represented 62 per cent of the tonnage preparing. The fall in tanker orders placed with foreign yards has helped to intensify competition, and British shipyards will be hard-pressed to maintain their share of world tonnage. At the end of 1953, shipbuilders in the United Kingdom (see Table II, also taken from Lloyd's Register's *Shipbuilling Returns*) accounted for 35 per cent of the world tonnage under construction and thus maintained the same position as in 1952. Whereas, however, the amount of shipping under construction in the United Kingdom rose by only 1 per cent, there were significant increases in the totals for all other European countries with the exception of Finland and Italy.

The Germans have again regained their position as the second greatest shipbuilding nation of the world, and the Deutsche Werft of Hamburg, who launched 145,800 gross tons, had a larger output than any other single yard

in the world. As in all other shipbuilding countries, orders have been falling, and the total order book at the end of 1953 was only about 1.4 million tons, compared with 2 million tons at the end of 1952. Since launchings in 1953 amounted to about 700,000 tons, German shipbuilders have only about two years' work on hand; nevertheless, in some ways they are in a stronger position than British builders, for the German Government are giving every encouragement to shipping and shipbuilding in order to restore the merchant fleet to something approaching pre-war dimensions. Large low-interest State loans have been available, and German shipbuilders have enjoyed important tax privileges.

A loan of 50 million marks to German shipbuilders was announced at the beginning of January. This follows a grant of 60 million marks made from Mutual Security "interests" funds. Moreover, credits of 170 million marks have been granted for the building of small ships. Even so, German shipbuilders are not very happy about the outlook. Herr Theodor Shecker, the managing director of Howaldswerke, is reported to have said that "Our shipbuilding will unavoidably contract in volume if existing tax facilities cease without a simultaneous lowering of the rate of interest in the capital market."

Direct subsidies are generally avoided as a means of assisting shipbuilding industries. Even in Japan, where, despite cheap labor, costs are substantially higher than in Europe and where the tonnage under construction fell off seriously in 1953, the Government has preferred to give indirect aid. This takes the form of a reduction in the interest rate charged by the Bank of Japan on loans of foreign exchange for iron and steel manufacture, which cuts the price of steel imported from the United States by about £9 10s. per ton; a reduction in the interest rate on loans to shipbuilders by the Development Bank and commercial banks to 5 per cent from anything up to 11 per cent; and a system of tax reliefs. As a result, shipbuilding costs are expected to be cut by about 11 per cent, but even so the price of Japanese freighters will probably be 3 or 4 per cent above the international level. There is, of course, no guarantee that Japanese shipbuilders, anxious to keep their yards employed, will accept foreign orders at uneconomical prices, and their ability to give quick delivery may, in any case, bring them business. Home orders should keep about half of their capacity fully occupied, for the Government shipbuilding program provides for an output of 300,000 gross tons per annum, of which about 70,000 tons will be tankers. One of the Japanese yards, the former naval establishment at Kure, leased by National Bulk Carriers Incorporated, has been enjoying a high level of activity; three tankers of 32,000 tons deadweight were launched as well as the Phoenix, previosuly mentioned; the keel was laid in May, and she was launched in October. One of the three ore carriers of 60,000 tons deadweight, which were subsequently laid down, has now been launched and is claimed to be the largest dry-cargo vessel in the world.

ATOMIC PROPULSION

Direct subsidies to the shipbuilding industry in the United States have been discontinued, though shipowners are still receiving Government grants. Orders have fallen off completely. All the major civil shipbuilding contracts will be completed in the current year, and there are no definite prospects of

new orders. This follows a record peace-time output in 1953 of 530,000 tons gross, compared with 467,545 tons in 1952. The Bethlehem Steel Company's Shipbuilding Division launched a total of 247,500 tons in major ships from their three yards; one of these, Sparrow's Point, achieved 125,093 tons. The experience of the United States Government in subsidizing merchant shipbuilding has not been encouraging. Since the outbreak of the Korean war, 21 Mariner-class fast freighters, of 12,900 tons and capable of 22 knots, have been built; but, though these were offered to private operators at prices well below cost, only one company, the Pacific Far East Line, who recently obtained an operating subsidy, have come forward as prospective purchasers. United States shipbuilders are now looking primarily to naval orders to keep them employed. The Government's projected program is for a third giant aircraft carrier, estimated to cost $210 million, 14 destroyers, minesweepers and similar craft, and 150 landing craft.

One of the achievements of United States naval construction is, without doubt, one of the most significant shipbuilding developments of recent years. The atomic-powered submarine Nautilus, which was launched at Groton, Connecticut, on January 21, will be able to stay submerged for more than 50 days and, is said to be able to outrun, either submerged or on the surface, most of the world's ships. It has several disadvantages, however, not the least being the high cost of about £18 millions. The atomic plant is expensive, and, with a displacement of more than 3,000 tons, the vessel may be difficult to maneuver, offering a substantial target for detecting devices. Nevertheless, the Nautilus heralds a revolution in naval strategy as well as in ship propulsion. A second atomic submarine, the Sea Wolf, is already under construction at Groton.

In the British naval program the emphasis is on anti-submarine and mine-sweeping craft. Expenditure on shipbuilding, repairs etc., will be increased this year by £21.7 million to £177.9 million. This includes completion of three aircraft carriers and work on a fourth. Outlay on new vessels is actually reduced. Research in shipbuilding and marine engineering is as active in the United Kingdom as in the United States. To take an example, the development of marine gas-turbine production is more advanced in the United Kingdom than elsewhere. Such notable recent launchings as the Orsova, Arcadia, and Saxonia bear witness to the continuing high quality of British ships. The problem of high costs requires urgent attention, but, despite increasing competition, British shipbuilders should hold their own. They have the means and ability to maintain the British merchant fleet as the most efficient operating unit in the world; it is only to be hoped that sufficient orders will be forthcoming before it is too late.

Table I. United Kingdom: Shipbuilding Analysis

Year and Quarter	Commenced		Launched		Completed		Under Construction		Preparing	
	No.	Tons	No.	Tons	No.	Tons	No.	Tons	No.	Tons
1952—March	56	324,831	62	327,141	55	267,511	356	2,270,612	324	2,393,703
June	57	205,641	62	309,018	68	405,600	343	2,076,241	321	2,531,623
September .	52	267,648	61	291,276	49	266,255	343	2,062,482	327	2,684,263
December .	63	389,800	66	373,177	66	324,438	336	2,146,402	306	2,606,478
1953—March	51	305,343	47	227,691	64	310,821	323	2,132,903	288	2,454,894
June	61	350,323	62	399,438	65	356,788	317	2,123,565	274	2,391,281
September .	47	289,233	57	323,414	47	218,967	316	2,190,329	273	2,286,174
December .	55	334,451	55	366,145	57	363,687	313	2,173,709	260	2,157,830

Table II. United Kingdom: Shipbuilding Analysis by Type of Vessel. (December, 1953)

Type of Vessel	Commenced		Launched		Completed		Under Construction		Preparing	
	No.	Tons	No.	Tons	No.	Tons	No.	Tons	No.	Tons
Passenger ..... Passenger and cargo	2	27,800	1	7,700	4	52,496	16	258,000	10	48,980
Cargo liner	18	101,980	15	101,200	8	63,492	80	523,227	84	648,550
Cargo tramp	3	17,950	3	13,750	5	33,764	30	163,310	27	171,455
Oil tanker	16	176,946	23	230,794	22	200,589	98	1,151,404	93	1,245,010
Collier	1	3,400	2	6,760	1	1,779	8	22,920	7	18,360
Coaster	2	1,500	3	3,097	3	2,628	20	21,196	8	10,990
Miscellaneous	13	4,875	8	2,844	14	8,939	61	33,652	31	14,485

Table III. World Shipbuilding: Gross Tonnage Under Construction

	December, 1952				December, 1953			
	For Home Owners		Total		For Home Owners		Total	
	No.	Tons	No.	Tons	No.	Tons	No.	Tons
United Kingdom	240	1,474,559	336	2,146,402	223	1,568,828	313	2,173,709
Other British Commonwealth countries	30	149,591	36	168,991	38	177,875	39	179,577
Belgium	10	36,600	23	120,700	9	55,939	26	142,459
Denmark	19	82,698	27	139,673	25	126,700	29	143,880
Finland	3	4,773	23	29,630	—	—	25	36,946
France	48	329,492	53	394,692	38	304,612	48	423,081
Germany	116	304,306	158	514,729	88	287,253	140	633,904
Italy	35	340,883	54	367,653	38	347,834	42	352,404
Japan	49	297,295	67	567,095	71	287,255	79	381,807
Netherlands	61	159,044	138	375,869	72	171,420	141	490,989
Norway	43	152,874	43	152,874	49	175,935	49	175,935
Sweden	31	195,230	53	348,075	28	164,968	56	408,748
United States of America	66	539,858	75	679,815	42	434,177	49	555,782
Other countries	91	107,192	93	112,387	100	195,655	100	195,655
Total	842	4,174,395	1,179	6,118,585	821	4,298,451	1,136	6,294,876

FACTORS AFFECTING THE DESIGN OF A RIVER TUG.

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The river tug is a very peculiar vessel of many requirements. It is, also, one most frequently met with, for the reason that it is the chief instrument in mass-transport of goods, this aspect of traffic, in its turn, being the main activity on inland waterways.

As the low cost of operation is the most important feature to assure in a tug, the designer should aim at selecting the three main components of the vessel, viz. the hull, the engine and the propeller, of such characteristics, as to produce by their harmonic cooperation the essential elements of operational economy, namely—

— small resistance of hull

— high efficiency of energy-transforming plant,

— high performance of propulsive equipment.

If one were quite free to make the choice of the main components at will, the design of the vessel would be rather a simple matter because their respective functions are governed by known mechanical or thermodynamic laws; their optimal performances do not occur in the same time, it is true, but despite the oft contradictory nature of the governing laws, it would not present great difficulties for a designer to find out conditions of maximum efficiency of the whole, by which procedure one could hope to obtain an economical sea-going tug.

Anybody could design a sea-going tug on these lines, but when we are confronted with the task of designing a river tug, the procedure becomes inadequate. The job is much more delicate and thought-absorbing because the selection of components *on their own merits* cannot be freely made, for the reason, that their individual and joint actions are severely influenced by many external factors. For in con-

trast with conditions on sea, offering almost unrestricted freedom to development of a sea-going vessel, the impeded development of the river tug has produced a type of ship inherently more difficult to design and to operate.

The factors which have greatly injured the natural development and the economy of operation of the river tug, incidentally complicating the whole system, are rather numerous; some of them depend on the nature of the ship's components alone, others are independent of the structure of the vessel, such as the navigational features of the waterways, for instance, or directional and volume characteristics of the traffic—to mention the most significant amongst them. They are of primary importance for economical operation of the tug, hence for the selection of type.

The main particulars of the vessel are also dependent on navigational characteristics and on the nature of the traffic.

We will now proceed to investigate the influence of the foresaid navigational and traffic factors upon the economy of performance of their reaction upon the design of a tug.

THE INFLUENCE OF NAVIGATIONAL CHARACTERISTICS OF THE WATERWAY

The Current. The speed of current in a waterway is a factor to which, for the most part, the reduced operational economy of the river tug can justly be ascribed. For obvious reasons it increases the resistance of a vessel advancing against it. As the increase follows a parabolic law, it is not made good by reduction of resistance on downstream travel. Thus, the current appears as a negative factor of the motion in a moving ambient. Moreover, the power needed to overcome the increased resistance follows also an inverted parabola of a much steeper gradient than before, so that the negative balance between upstream and downstream power demand is still greater. It is often the case that the twofold increase of speed, for instance, requires the fivefold increase of power. The power, of course, is supplied by the tug and we can see at once, what an enormous difference the current makes in the economy of transport by water, bearing in mind that of the total transporting costs more than 70% are generated by the tug alone. Furthermore, a current of 8 to 10 km/h may reduce to nothing the relative economical advantage of water transport as compared with railway or road transport.

So much for the factor current as it affects the economy of operation. Its immediate reaction on design is the increase of engine power, engine room, crew's quarters, i.e., the increase in the size of vessel with everything else it implies.

A current of variable speed is, in a way, still more exacting than the one of constant value, for besides the size of ship, it affects also the type of engine. We will explain this later on. For the moment let it suffice to say that a current of constant or nearly constant speed can conveniently be overcome by an engine of non-flexible output, such as a Diesel motor, which at the present time is the cheapest and most efficient machinery for the purpose; the mastering of a variable current, however, requires a flexible machine.

The Depth of Water. The next factor of great concern is the depth of the waterway. Its obvious importance for

the economy of transport relates more to barges in tow than to the tug proper, although, as we shall see, it does not leave it unaffected.

The depth of water determines the draft of barges, this item being the chief particular on which the size of a vessel depends. Now since we are engaged in mass-transport of goods it is clear that the big-sized barge of ample capacity of holds, is more economical, particularly on long-distance travels, than the small sized one. Having but little water beneath the bottom, a barge can be made of large capacity only if its second main particular—the beam—be increased, the increase of length being oft checked by the other waterway characteristics, such as the size of locks, sharp bends, etc., or by mere structural considerations. No waterway is narrow enough as a rule, to call for serious limitations in the beam of the vessel; it is then the case, that the large holding capacity of barges is easily obtained by increasing their breadth.

The increase of breadth beyond certain limits, however, is the classical means for excessive increase of resistance. Amongst many causes of ships resistance, the ratio of depth to beam is not the least. Owing to a large B this ratio is twice to three times smaller in a river vessel than in a sea-going ship of the same displacement, the fact appearing in form of increased resistance.

The same holds good for the tug. It is true, though, that we have not to deal here with the cargo, but the stowing of machinery as a heavy concentrated load has a similar effect upon the shallow draft vessel.

In addition to impairing the performance of hull (resistance—augment) the shallow waterway affects also the machinery in that it determines the type of propelling equipment, the later in its turn involving a particular type of engine to assure an efficient connection thereto.

Both characteristics, the depth of water and variable current—to return to it for due explanation—are *prima facie* responsible for the selection of propelling equipment. Their joint influence is rather disappointing in that it makes the choice of the conventional and efficient 4-blade screw-propeller rather equivocal, the alternative being the paddle-wheel. Now, there are many objections to a paddle-wheel, to wit: the weight, the size, the price, the exposure to damage, the maintenance costs etc., to name but a few, compared with the competitive screw-propeller. Its efficiency is not higher, either, but its chief claims are that it can do heavy work in shallow waters much better than the screw-propeller and that in particularly bad cases of shallow rapids it is really the only means of propulsion for sized ships.

No doubt, the active area of the propeller of a heavily loaded, highly powered tug ought to be rather large to absorb efficiently the power supplied by the engine. The geometry of the wheel allows this area to be easily got by lengthening the floats across the width of the waterway, whilst the increase in diameter of a screw-propeller in the depth of water is checked by insufficient depth.

Furthermore, the passage of rapids usually puts the overloading capacity of a tug to the severest test. Here we may recall that the floats are less sensitive to overloading than the blades of screw-propeller, the efficiency of which sinks rapidly with increasing overload. In bad waters for a screw-propeller, the wheel can produce a tugging force about 12 to 18% greater

than a screw-propeller. If we imagine the waterway characteristics sufficiently bad to make the work of the screw-propeller very unproductive then, of course, the floats will appear as above competition.

A functional draw-back of the paddle-wheel is its very slow dynamics, the number of RPM hardly exceeding 50 in European type with excenter actuated floats. To achieve a straightforward and simple connection with the engine—direct coupling—a slow machine ought to be provided. A slow machine is just as bad as a slow paddle-wheel, and a little worse, and that brings us to the next series of influencing factors originating from ship's component parts.

THE INFLUENCE OF THE SHIP'S COMPONENTS

The Hull—The hull is a negative factor in the economy of a tug's performance. It serves for stowage of machinery and propelling equipment, for which function it absorbs about 25% of the generated energy when moving at normal operative speed. When this speed is doubled the tug absorbs *all* the energy generated.

The consumption of energy depends on resistence to motion. Many causes go to contribute to its making, the chief static ones being the dimensions of the hull. It is then a matter of common sense for a designer to keep these as small as is compatible with the good holding qualities and the lateral stability of the tug.

The best design for a tug is one which, while fulfilling all requirements, provides the smallest hull.

The Machinery. The participation of machinery in the total cost of transport amounts to about 35%. The high technical standard of machinery is evidently an important element in the economy of a tug's performance. At present there are two kinds of machines suitable for marine propulsion —a Diesel motor for screw-propeller and piston steam engine for a paddle-wheel. The steam turbine is a rare incident on European rivers owing to the inferior efficiency of minor sets as compared with the Diesel motor, and the necessity of gearing.

The gas turbine, probably the universal marine engine in a not very distant future, will not be likely to make account of herself in the next decade on inland waterways.

The design trends of the Diesel motor for marine purposes are favouring the increase of speed. That makes it a little awkward for the screw-propeller, the efficiency of which is good at reduced speed. To make the best of both, high speed motors in Europe have sometimes been connected to slow-turning screw-propellers by intermediate mechanical or electrical transmission gearing.

For relatively small installed powers, such as in river tugs, this experiment is not to be recommended; its initial economy of drive is soon made problematic by the rising losses in transmission gearing. Besides, it increases the weight of the tug.

The small-output Diesel motor is about at the end of its development and its present-day efficiency at moderate speeds (about 300-400 rpm) is quite satisfactory. So is the efficiency of screw-propeller at the same speed. Any further improvement of either of them would only result in appearance

of difficulties of another nature. There is no pressing need for it and it would not do to try to enhance forcibly their joint performance by inserting between them some energy-consuming mechanisms of questionable economic value. Thus, there is apparently little trouble in selecting the proper machinery to suit the requirements of a screw-propeller. The suggested direct coupling produces a tug of rather high performance, as a result of small resistance of hull, satisfactory efficiency of machinery and good propeller performance.

The difficulties of the designer arise only with the application of the paddle-wheel.

To its mechanical, operative and functional disadvantages the inconveniences derived from its transverse position in ship and the elevated position of its axis, may now be added. In such a position the direct drive offers the simplest and/or the best solution.

We will now investigate the influence of the paddle-wheel upon the economy and design of the tug and see first how it affects the hull and the machinery in the direct drive variety.

The wheel being a slow-rotating mechanism the engine must be of the same kind. This eliminates the application of the efficient motor and enforces the choice of steam engine. Since RPM are rather low (50), the generation of *"big horses"* can only be effected by increasing materially the size of the engine. This produces a heavy, slow running machinery with a low pressure working medium—nearly all the elements of low efficiency. Actually the thermal efficiency of such an engine is about half that of a Diesel motor.

Moreover, the introduction of heavy boilers makes the hull longer, wider and heavier; its resistance is increased by about 20%, whilst the *economical* efficiency of energy-transforming plant is reduced by at least 10%, generally depending, however, on the price of fuel. In short, the operation cost of this type of ship is about 34% higher than that of a motor driven screw tug. Remembering that the tugging capacity of a paddle-wheel in shallow waters is 12 to 18% greater, the net loss appears to be about 20% compared with the screw-propeller drive.

A loss of 20% is a serious matter and it is no wonder that many designs have been developed to reduce it. All were conceived on the line of combining the good towing capacity of the archaic paddle-wheel with the good, economical performance of the Diesel motor, by introducing intermediate electrical or mechanical transmission machinery.

All that could be said of such endeavours is that the first has found favour with manufacturers of electric machines, the second with corresponding engineering industries. The replacement of a heavy steam engine with a boiler by Diesel motor plus electro-generator plus eletro-motor plus gear mechanism *actually has not yielded a less voluminous ship.* It is true that the "bench" trials were rather encouraging as regards the economy of production of tugging force, but many factors which go towards the making of this economy had to be estimated and some of them, at least, could not be properly assessed at all, so they were left out of reckoning, for instance, the reduced general safety of drive owing to the introduction of a number of machines and mechanisms (between the prime mover and the paddle-wheel) doing the same job, delay in response to wheel-house commands, enlarged field of possible breakdowns with simultaneous reduction of the crew's ca-

pacity to mend them on board and finally the elimination of flexibility of drive.

A great point in a slow running, long-stroke piston steam engine is its potential capacity for delivering considerable surplus power above the nominal HP. The compound steam engine, for instance, can be relied on to work with 50% overload for practically unlimited period of time and even with 70% for a short time, assuming the adequate supply of steam. For work in shallow waters with variable strength of current the flexibility of power is, indeed, very necessary and highly appreciated by the personnel, for the reason, that a tug powered in this way can make the passage of bad waters without splitting the tow, even if the current may have caused a very substantial increase in its resistance.

Unless fully instructed about actual difficulties, loss of time and low economy of transport by means of an intermittently split tow, the designer may feel inclined to prefer for shallow waters, too, the highly efficient Diesel motor, even with its undesirable appurtenances, to a steam engine of rather antiquated aspect and conception.

The Propeller. The evils of uneconomical tow in bad waters originate, as we have seen, from our inability to connect effectively, if not directly, a flexible prime mover of high performance to an efficient propeller, unaffected by the speed of current and the small depth of water.

The claims put on a river tug are obviously rather hard to comply with.

As regards the prime mover, in a not very distant future we shall be possessing one of extraordinary flexibility—the gas turbine, her overload capacity exceeding about three times that of a compound steam engine. But whether her efficiency will equal that of a Diesel motor, remains to be seen.

The outlook for development of a propeller possessing the necessary features to meet the rather capricious demands of a waterway is at present not so good. The variable pitch propeller is likely to be developed into an implement efficiently adjustable to the changing load. But that it will yet shrink from shallow waters is unfortunately to be expected. Besides, for smaller units it is rather expensive. The development of a paddle-wheel is a hopeless proposition. The attempts to accelerate it have failed.

The latest experiments with a Voith-Schneider propeller are not encouraging.* Although the solution is apparently nearer at hand with this type of propeller than with any other, with respect to economy of work in deep waters, the latest "water tractors" BIENE and HORNISSE, manufactured by the German pioneer firm J. M. VOITH—specified in the issue of ASNE quoted—are rather small units to be of importance for bulk-transport. Nevertheless, the last named tug-boat has but 2 x 150 HP to show for a draft of 1.60 m. Such draft implies the least depth of water of 1.80 m, which would be considered very favourable all the year round in as great a river as the Danube. Moreover, it would allow the operation of a very efficient screw-propelled tug about four times as powerful, such vessel corresponding more to the general needs of bulk-transport on a big river.

But in its original setting, at the raised stern of a ship, the good functioning of V.S. propeller is almost as unaffected by shallow waters as the

*See Journal of ASNE, Vol. 65, No. 3, pp 639.

paddle-wheel; it can easily be adjusted to any change of load and is fairly efficient where a high overload is concerned. Not as simply and compactly built as a common screw propeller, it is, however, much more so than the paddle-wheel. Owing to the position of its axis of rotation, the connection to the prime mover must be of indirect variety, but this, too, is much more easily achieved than with a paddle-wheel.

However, in its further development this type of propeller, too, will probably not prove to be a first class creation in the line of propelling equipment for river tugs, as we expect the gas turbine to be in machinery, but it may be the second best. The application of the water tractor, on the other hand, will have a field of action restricted to harbour service.

The efficient propeller for a river tug-boat still remains a problem.

THE INFLUENCE OF TRAFFIC CHARACTERISTICS

The navigational characteristics of waterways and considerations on the economic cooperation of ship's components, as the most important influence factors, have been instrumental in determining the type of propeller, the kind of machinery and the general outline of hull, including the draft. The next step for the designer would be the determination of power and hereafter the two remaining main particulars, as mere structural contingencies of the selected power; provided, of course, that some peculiarities of the waterway, viz. sharp bends, narrow passes, oscillations in waterlevel, size of locks, etc., have not fixed them beforehand.

To a certain extent the general outline of the hull, as the outcome of the two first named series of influence factors, contains also the indication of ultimate dimensions of the ship, i.e. her *greatest* dimensions. But though these are, as a rule, the most economical, we cannot procede on such knowledge when designing a powered ship because the external shell pattern is of secondary importance to a tug's economy, the primary being the power.

The prospects for useful application of power generated in a tug depend on the amount of work to be done in transporting goods and for informations on that point we must turn to traffic characteristics. The information required is to be found in records on the density and the direction of traffic.

The Density of Traffic. We will suppose that the size of barges on a particular waterway has been appropriately selected in accordance with the same traffic and navigational characteristics and that the "density" of flow of goods, as the influence factor determining the load for the tug, will now be represented by a number of loaded barges, the resistance of which is to be overcome by the power of the tug.

How strong the tug ought to be will now depend on the average number of barges to be towed all the year round, their size and the speed of tow. The latter is not to be computed from traffic characteristics nor to be set arbitrarily by the designer. We are referring to "economical" speed, that is, the speed at which the total costs of transport are at their minimum value. The very interesting calculation of the speed exceeds the scope of this work; for the present it may be taken at about 8-9 km/h in still water.

The Direction of Traffic. To attain economical speed of travel against a current implies the necessity for the tug to develop a greater power; the ultimate determination of HP is influenced, also, by the direction of flow of goods and the strength of the current. The flow of the bulk of goods may often be undirectional; in this case the economical speed up the stream is somewhat greater, remaining, however, unchanged for downstream transport.

SUMMARY

The design of a river tug is affected by a series of factors originating from three main causes: navigational characteristics of the waterway, functional characteristics of ship's components and traffic characteristics.

1. The characteristics of the waterway determine the draft of the vessel and the type of propelling equipment.

2. The characteristics of the ship's components decide the choice of machinery.

3. The traffic characteristics plus "economical" speed determine the power.

DESIGN CONSIDERATIONS— LAMINATED PLASTIC CONSTRUCTION

COMMANDER A. C. BUSHEY, JR., U.S.N. Retired

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During his last year of active duty, he served as the Senior Assistant Supervisor of Shipbuilding and Naval Inspector of Ordnance and Assistant Industrial Manager, Baltimore. During World War II he was attached to the South Pacific Command, later serving as officer in charge of shipbuilding and ship repairs in New Zealand and commanding officer of the U.S. forces in Auckland.

The late King of England invested him as an Honorary Officer of the Military Division of the Most Excellent Order of the British Empire. He was also made an Honorary Commander in H.M. New Zealand Coast Guard and for his service in the South Pacific he was decorated with the Bronze Star Medal.

Laminated plastic construction, utilizing low-pressure or contact resins, has achieved rapid growth during its ten years of existence. It has many facets. This paper is primarily intended to present design considerations involving manufacture of monolithic objects composed of fibrous glass cloth or fibrous glass mat, or both, as laminates and with polyester resin serving as the bonding agent. As in reinforced concrete design, the plastics engineer must provide continuity of reinforcement and, in a great many instances, provide reinforcing fibers at right angles such as are found in cloth or which may be obtained by alternating mat laminates at right angles to each other.

DESIGN-GENERAL

In contract design, laminated glass plastic construction lends itself to specification either by function or detailed delineation.

In both contract design and preparation of shop drawings, inspection of materials received and supervision of processes should be specified. In many

cases test specimens for determination of physical properties should also be specified.

Until specifications for the basic materials receive general acceptation, inspection of materials may usually be limited to insurance that the quantities and labels agree with the order. Before placing the order, however, designers should obtain the manufactureres' specifications, or preferably, visit the manufacturers' plants to obtain first-hand data on the properties of the materials, their peculiarities and limitations, and recommended techniques.

High quality laminated glass plastic production will be obtained by using any of the well known methods, i.e., hand lay-up, one mold with either vacuum blanket or pressure bag, matching molds or with presses. The economics of laminated glass fabrication has often centered around the cost of equipment for the various methods. The oft-forgotten factor is the cost of insuring quality of production. This factor seems to be inversely proportional to the cost of equipment. To a large degree the method of production depends upon the quantity of items to be produced. Regardless of quantity, quality control must be specified.

PHYSICAL PROPERTIES

Polyester resins, when poured as castings, possess physical properties akin to oak. Their tensile and flexural strengths are practically identical. The compressive strength and the specific gravity of resin are both fifty (50) percent greater than oak. The modulus of elasticity, however, of the resin is about one-third of the modulus of oak.

When polyester resins are used to thoroughly impregnate and bond layers of fibrous glass cloth or mat, and where the glass content is thirty-five (35) percent by weight or more, the resulting laminate has physical properties, which, execept for the specific gravity, are more than three-fold those possessed by pure polyester resin castings. Laminated objects of this type may be classified under *laminated glass plastic construction.*

When the glass content is below thirty-five (35) percent, when short lengths of fibrous glass, regardless of the content percentage, or where presently known materials or fibers other than glass, are used to reinforce the resin, it will be found that the physical properties of such construction, which may be labeled *reinforced resins,* fall far below the rather high properties obtained in laminated glass plastic construction. In fact, the values appear to drop rapidly downward toward the physical properties of wood and polyester resin. This type of construction has an important function for many reasons; among them its ready susceptibility for mass production and the resulting object being of monolithic construction.

When long glass fibers of extremely small diameter are run in the same direction purposely in design and are bonded with polyester resin, such fabrication may be denoted *oriented glass plastic construction.* Here tensile strength equal to that of steel can easily be achieved. The modulus of elasticity will be approximately 2,000,000 pounds per square inch.

TYPICAL PHYSICAL PROPERTIES OF VARIOUS MATERIALS

Material	Wood (Douglas Fir)	Steel (Medium)	Bronze (Mn)	Aluminum for Boatwork	Polyester Resin Castings	Laminated Plastics Note 1 Note 2
Flexural Strength, Flatwise, PSI	11,200	60,000	55,000-115,000	13,000-42,000	11,950	30,000
Flexural Strength Edgewise, PSI		60,000	55,000-115,000	13,000-42,000	11,950	37,000
Flexural Modulus of Elasticity, Flatwise, PSI x 10^6	1.64	29.0	14.5	10.0		1.13
Flexural Modulus of Elasticity, Edgewise PSI x 10^6		29.0	14.5	10.0		1.36
Tensile Strength PSI	10,750	60,000	55,000-115,000	13,000-42,000	9,060	27,000
Tensile Modulus of Elasticity, PSI x 10^6	1.2	29.0	14.5	10.0	0.5	1.76
Compression, Flatwise, PSI	920	60,000	120,000		10,900	44,000
Compression, Edgewise, PSI	6,720	60,000	120,000		10,900	21,600
Shear—Parallel to Long Edge of Sheet, PSI	1,130	45,000				3,200
Shear—Parallel to Short Edge of Sheet, PSI	190	45,000				3,300
Izod Impact—Edgewise Ft. lb. ÷ in. Notch		32			0.35	26
Specific Gravity	(Dry) 0.44	7.85	7.4-8.9	2.5-2.8	1.2	1.64
% Water Absorption	48	0	0	0	0.1	0.17

Note 1: Glass Content—47% by weight
Resin Content—53% by weight

Note 2: Properties improve by increasing glass content and diminish by decreasing the glass content.

MODULUS OF ELASTICITY

The modulus of elasticity of laminated plastics is approximately 1,800,000 pounds per square inch. This factor has been exploited in the manufacture of laminated plastic boats, where many of the commercially made craft have

but little framing and are non-rigid. The empirical rule in metal construction that the unsupported width of plates shall be not greater than forty (40) times the thickness has thus been completely disregarded. Here impact shocks tend to be cushioned by the low modulus of elasticity and the magnitude of stresses introduced by misalignment of structural members is lessened.

Because of the low modulus of elasticity, the selection of permissable deflections becomes the most important factor facing the plastics engineer.

The usual procedures are followed in the design of beams and panels. Deflection under load should also always be considered. This deflection depends on the shape and arrangement of members and also on the modulus of elasticity. Or, the flexural rigidity of a beam is its E I. Occasionally, as in boats, the bending afforded by the low modulus of elasticity of laminated plastics is an asset. In not as many instances as the designer may at first suspect, will rigidity be required.

Caution should be exercised before using a different material as a reinforcing member inside a laminated plastic member. If a different material is used, the coefficients of expansion of the two materials should be nearly alike, sliding of the two materials and excessive shearing stress over the surface of contact should be avoided by provision of mechanical bonds as no reliance can be placed in an adhesive bond, and the cross-sections of the two materials should be calculated by using the familiar methods which determine equivalence. If steel and laminated plastic were used to form a rectangular beam, the laminated plastic part in bending would be equivalent to a much narrower web of steel. Equivalence would be provided by making the webs of both material of the same height, but the laminated plastic part of the web should be $\frac{30}{1.8}$ times the thickness of the steel part.

$$(E_s = 30,\ E = 1.8)$$

It is usually better practice to use preforms (previously fabricated members of plastic laminates) instead of wood, steel or aluminum. Wood should never be used except for temporary molds because of its dimensional instability.

In metal construction beams of very narrow rectangular section sometimes collapse by sidewise buckling. In laminated plastics, beams of this type are difficult to produce if made integral with the structure. The nearest approach to this type of construction is where the designer introduces a rim or flange around his laminated plastic object to provide stiffness. Here, failure does not present as much of a problem as excessive deflection under heavy load.

Laminated plastic beams can be rapidly fabricated by several processes in angle and other shapes, or of rectangular cross-section with pleasing architectural proportions. Such rectangular beams are made with a lightweight core material, the core merely serving as the mold for the casing of laminated plastic.

In the design of panels it should be remembered that the radius of gyration of a flat plate is equal to 29% of its thickness.

The following formulae are given for ready reference:

Flexural stress at extreme fibers in beams

$$f = \frac{M}{I} = \frac{Mc}{S}$$

Flexural stress at any fiber in beams

$$f = \frac{My}{I} = \frac{M}{S}$$

M=Bending Movement.

c=Distance from Neutral Axis to Extreme Fiber.

y=Distance from Neutral Axis to Fiber under Consideration.

I=Moment of Inertia.

S=Section Modulus.

The allowable working flexural stress to be used in the design of laminated plastics is 7,500 PSI.

TENSION

Laminated plastics are unlike structural steel with respect to yield and ultimate strengths. In steel the yield strength is about one-half the ultimate. In laminated plastics the yield strength is almost the same as the ultimate strength. The negligible spread between yield and ultimate in laminated plastics does not provide a factor of safety against tensile fracture.

Until more experience is obtained in quality control of laminated plastics the allowable tensile working stress should be taken as 7,500 PSI.

COMPRESSION

It is accepted that the critical load which causes the buckling of a column is not dependent upon the strength of the material but only upon its dimensions and the modulus of elasticity of the material.

It is a safe rule in the design of laminated plastic columns for $\frac{l}{r}$ not to exceed 30. Then use 7,500 PSI as the compressive working stress.

In extremely short columns where direct compression is flatwise on the laminates use 15,800 PSI as the compressive working stress.

The following formulas are given for ready reference:

Compressive Stress in Columns Concentrically Loaded

$$f = \frac{P}{A}$$

Compressive Stress in Columns Eccentrically Loaded

$$f = \frac{P}{A} + \frac{Mc}{I}$$

P=Load

A=Area

M=Bending Moment

c=Distance from Neutral Axis to Extreme Fiber

I=Moment of Inertia.

SHEAR

The allowable working shearing stress to be used in laminated plastics is 1,000 PSI. This value and that of the modulus of elasticity are both low in comparison with steel. These are in distinct contrast with the rather high allowable working stresses in flexure, tension and compression of laminated plastics.

Shear should always be investigated in the design of beams, columns and fasteners.

The following formulas are given for ready reference:

Average Vertical Shearing Stress

$$v = \frac{V}{A}$$

Horizontal Shearing Stress at any Section

$$v = \frac{VQ}{Ib}$$

V=Total Shear.

A=Area.

Q=Statical moment about the neutral axis of the entire section of that portion of the cross-section lying outside of the section under consideration.

b=Width at section under consideration.

I=Moment of Inertia.

CONNECTIONS

The design of connections and joints is just as important as that of the members themselves.

When metal rivets are used they should be stressed chiefly in shear and bearing rather than tension. When the fastener is subject to repeated tensile loadings, bolts should be used. The spacing of rivets and bolts should be calculated to prevent column failure of the laminated plastic parts between adjacent holes and to resist longitudinal shear.

Laminated plastics may be tapped to receive machine screws. If steel screws are used, the diameter of the screw should be at least fifty-three (53) percent of the depth of the penetration if it is desired to develop the full strength of the steel.

OBSERVATIONS AND SUGGESTIONS

From review of numerous designs with designers and fabricators some rules are suggested to aid those engaged in detailed design of laminated plastic structure and components.

The designer should strive to maintain the same thickness—the same number of laminates—in a given structure. Adequate stiffness can often be attained by providing a rim or flange around the object, such flange being of the same thickness as the rest of the structure. Frequently the stiffening member can be designed around the means of securing a laminated plastic component to the remainder of the assembly.

Fillets or bends should, if possible, have radii equal to eight (8) times the thickness of the material.

If holes or openings require reinforcement, it will be found desirable to review the calculations to determine if:

Increasing panel thickness to accomplish desired end is economical.

Provision of flange of same thickness is feasible,

Addition of preform is feasible or if

Metallic boss or collar is more desirable.

PROTOTYPES OF OTHER MATERIALS

Occasionally, the re-design of an object into laminated plastic is simple. The widespread substitution of laminated plastic standard pans (of the type used for waffle construction of concrete floor slabs) for metal standard pans has been a boon to builders because the corrosion problem has

been eliminated. In this instance, the designer merely had to select a thickness for the laminated plastic. The designer had a similar task in determining the thickness of corrugated laminated plastic roofing. Laminated plastic automobile bodies and fenders fall in the same category.

More often the plastics engineer is called upon to present a laminated plastic substitution for a combination wood and metal, a cast or a drop-forged object. Recently, the dielectric properties of laminated plastics have been exploited in many directions. In all of these instances, the engineer must concentrate on the function of his design, use stimulative imagination and endeavor to forget the previous construction in other materials. It is axiomatic that designs are predicated on the properties of materials and fabricating processes.

In evaluating many of the successful items of laminated plastic now in extensive use it was found that as a rule:

Where laminated plastics replaced pressed sheet steel or medium steel built-up items, the thickness of the laminated plastic was between 1.48 and 2.52 times the thickness of the steel. Values above 1.75 were usually found where the designer provided an end-product which would resist denting or deformation to a greater degree than in the steel prototype.

Where laminated plastic replaced wood, laminated wood or plywood objects, the thickness of the laminated plastic was between 0.371 and 0.405 times the thickness of the wood.

Where laminated plastic replaced bakelite the weight saving was always in excess of twelve (12) per cent.

Where laminated plastic replaced cast metal the weight saving always exceeded fifty-eight (58) percent.

BOAT DESIGN

Previous articles by the author in this Journal describe the development of laminated plastic boats. These articles are also descriptive of the processes and techniques used in fabrication. These data also furnish valuable clues to design. A brief resume is furnished for general guidance.

More than in any other laminated plastic construction, the method of boat fabrication influences design. Here the advantages, limitations and the approaches to exactitude of quantity and quality control which can be utilized to the fullest in each method are exploited in the consideration of each facet of design.

The lines of boats and boat construction in wood and the shape and construction of metal life boats are the result of evolution. Proper design in this field of endeavor is a function of experienced naval architects who have specialized in boat design. Hence a boat designer should always be associated with the plastics engineer in laminated plastic boat design.

One method of design is to follow the previous design in wood, to make a slight allowance for the weakness of the wooden structure caused by the many joints and fasteners and to provide equivalent sections of laminated plastics throughout. Such design invariably results in an excellent boat of monolithic construction which usually weighs about ten (10) per cent less than the wood prototype.

A much better method of laminated plastic boat design is that used by commercial designers to a large extent and by the U. S. Navy in the design of the 26-ft. motor whale boat. In this method, a few longitudinal strength members, such as keel, gunwale and another at mid-height, with transverse stiffening at the thwarts constitute the framing. In such design the skin of the boat is fully stressed and is usually thick enough to resist high impact shock loads. The boats are usually monolithic throughout or are two (2) monolithic structures joined together in the vicinity of the waterline.

A method which will be used in large production orders of small boats is to sectionalize. Laminated plastic sections susceptible of expeditious production will be made in presses. In some instances, these sections will be joined together with fasteners and/or resin adhesives to form a complete boat. However, in another method, the boats will be made in two or three sections of size permitting transportation by the family automobile and then assembled on the beach by simple mechanical fasteners.

Boats constructed in accordance with the two previous paragraphs have weight savings of eighteen (18) to forty-three (43) percent over comparable wood boats. Because such design does not allow mathematical determination of sizes of the strength members, the laminated plastic boat designer should always specify the construction of a prototype and complete tests before production is started.

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MARINE SHAFTING ALIGNMENT

ACKNOWLEDGMENT

The April 1954 edition of *The British Motor Ship* published this article which discusses the influence of stern bushing "wear-down" on loading of propeller shaft bearings. The author is Mr. J. E. Richards.

The application of the theorem of three moments to propeller shafting leads to such complicated expressions for the loading of the bearings that general conclusions cannot readily be reached. The simpler approach is to work out the bearing loads for a definite shafting arrangement and investigate the effect of alterations to this arrangement. The initial alignment is assumed to be perfect and the variation of the loading of the bearings with wear-down of the stern bush is calculated. It is found that the distance between the three aftermost bearings and their heights relative to each other are the factors which have the greatest influence and consequently the results may be expected to give an indication of the effect of both initial misalignment and bending of the hull girder but these variables are much less important than wear-down of the stern bush.

Such calculations have been carried out by The British Shipbuilding Research Association for the shafting of a 17,000-ton d.w. Diesel-engined tanker, the "as fitted" shafting arrangement of which is shown in Fig. 1. In order to compare the arrangement of bearings adopted for this particular vessel with alternative arrangements, the change of loading of the shaft bearings with weardown of the stern bush has been calculated for the following conditions:—

Condition 1. Plummer blocks arranged as in Fig. 1.

Condition 2. The first plummer block moved forward 28½ in., the positions of the other plummer blocks remaining unchanged.

Condition 3. The first plummer block moved forward 57 in., the positions of the other plummer blocks remaining unchanged. As the shaft diameter of 21 in. adopted for this vessel on account of torsional vibration was much greater than that required by the regulations of the classification society, it was decided to repeat the calculations for a shaft diameter of 18 in. in order to see how the stiffness of the shafting affected the results. The degree of fixity at the engine coupling was unknown and hence it was necessary to carry out the calculations assuming two extreme

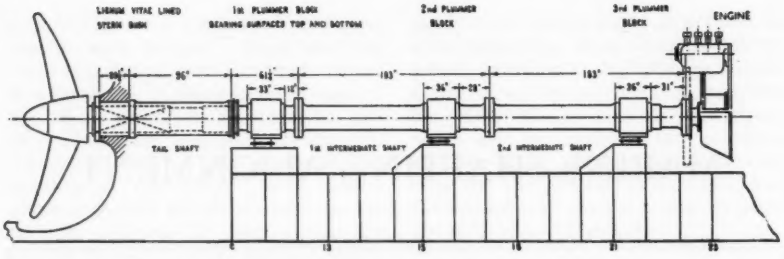

Fig. 1. General arrangement of shafting of the 17,000-ton motor tanker. Weight of propeller (allowing for buoyancy) = 20,300 lb. Diameter of shafting = 21 in. Weight of shafting = 98 lb./ft. run. Weight of brass liner of tail shaft = 8.9 lb./ft. run. Second moment of area of 21 in. diameter shaft = 9550 in.^{4} Second moment of 21 in. shaft plus liner = 10510 in.^{4}

conditions, a simple support and an encastré support, in order that some idea of the variation of the results with the end condition of the shaft could be obtained.

The results of these calculations are shown in Fig. 2, in which the loading of the bearings is plotted against weardown of the stern bush. After a certain weardown the loading of the second plummer block is reduced to zero and the curves in Fig. 2 pertain to the condition in which this plummer block is able to sustain negative loads. It will be seen from these curves that the loadings of the stern bush and after plummer blocks are not affected appreciably by the assumed condition of restraint at the engine coupling. Consequently the curves apply equally well to the after end of the shafting of an amidships machinery installation.

In Fig. 3 the bearing loads are plotted for the condition that the second plummer block is not able to sustain negative loads. In order not to confuse the issue the curves are given for the simply supported end condition only. It should be noted that if the lines for the loadings when the second plummer block is carrying no load are projected back, they give the loadings which would be carried by the other bearings if the second plummer block were removed.

It will be seen from Fig. 3 that the reduction in loading of the stern bush with wear-down is greater with the 21-in. than with the 18-in. diameter shaft. The effect of moving the first plummer block forward is to lessen the reduction of loading with wear-down and thus offset the effect of the larger-diameter shafting. The reduction of loading with wear-down is lessened when the shaft ceases to bear on the second plummer block and it will be seen that from this point of view there is something to be gained by eliminating this bearing.

With regard to the first plummer block, it will be seen from Fig. 3 that the probable loading of this bearing in service is very much higher than that deduced by simple design calculation as the loading increases very rapidly with wear-down of the stern bush. The presence of the second plummer block only alleviates the loading of the plummer block when the weardown of the stern bush is small. The effect of moving the first plummer block forward is

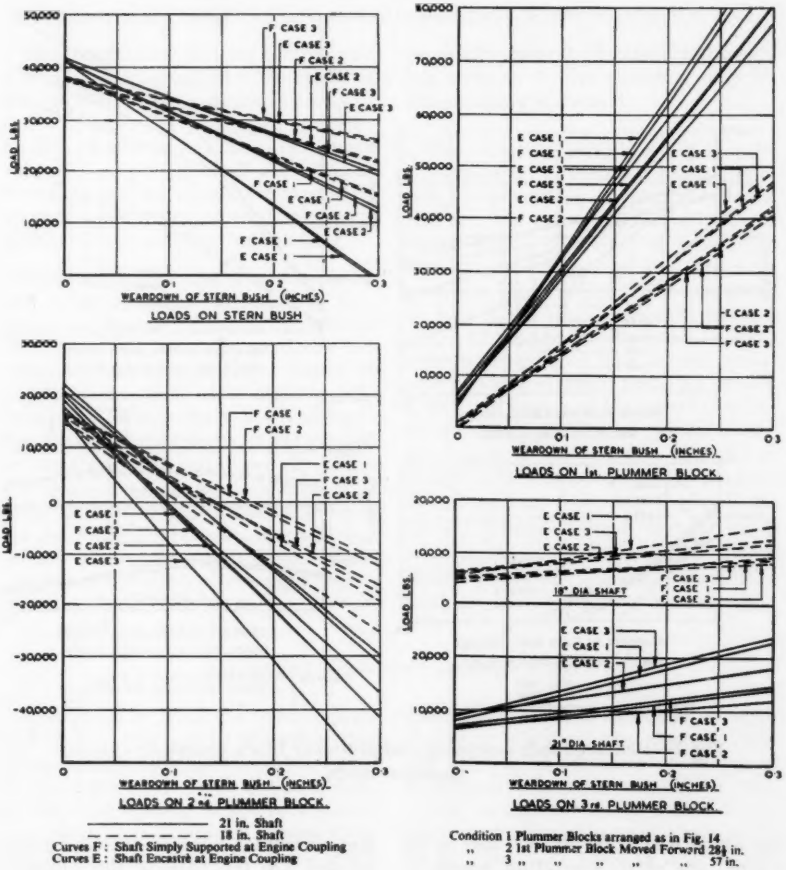
LOADS ON STERN BUSH
WEARDOWN OF STERN BUSH (INCHES)
LOADS ON 1st PLUMMER BLOCK
LOADS ON 2nd PLUMMER BLOCK
LOADS ON 3rd PLUMMER BLOCK
LOAD LBS.
21 in. Shaft
18 in. Shaft
Curves F: Shaft Simply Supported at Engine Coupling
Curves E: Shaft Encastré at Engine Coupling
Condition 1 Plummer Blocks arranged as in Fig. 14
2 1st Plummer Block Moved Forward 28½ in.
3 57 in.

Fig. 2—Bearing loads assuming 2nd plummer block able to sustain negative loads.

to reduce the loading, but this effect is not as great as that which arises from the change in diameter of the shafting. The projected area of the first plummer block is about 300 sq. in.

The second plummer block ceases to be effective when the wear-down reaches about 0.15 inches for the 18-in. shaft and about 0.10 inches for the 21-in. shaft. The loading of the third plummer block is relatively unaffected by wear-down of the stern bush.

In a recent paper, some very interesting results are given of measurements made of the bending stress in the tail shaft of a T-2 tanker just forward of the propeller. The bending stress due to the weight of the propel-

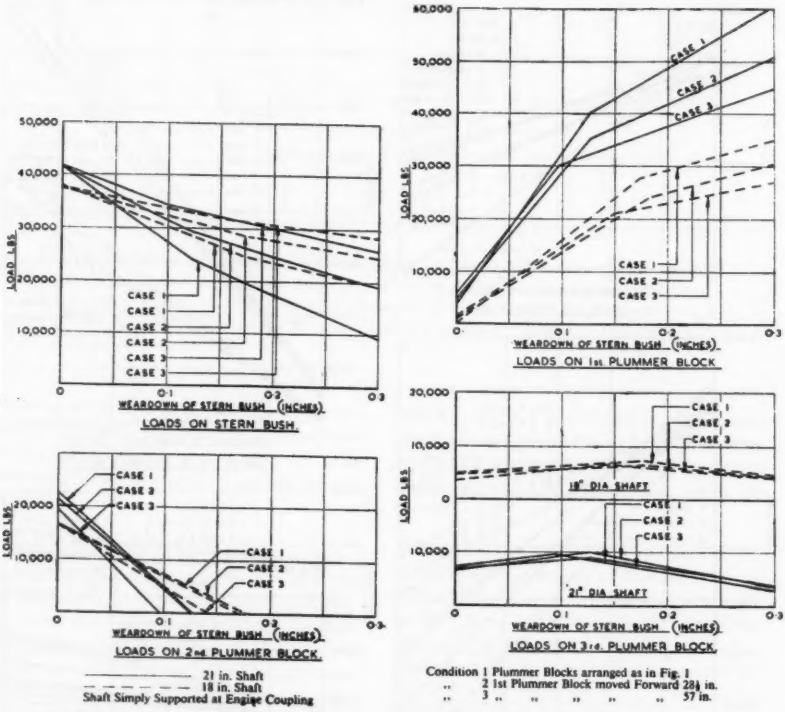
LOAD LBS.
WEARDOWN OF STERN BUSH (INCHES)
LOADS ON STERN BUSH
LOADS ON 1st PLUMMER BLOCK
LOADS ON 2nd PLUMMER BLOCK
LOADS ON 3rd PLUMMER BLOCK
18" DIA SHAFT
21" DIA SHAFT
CASE 1
CASE 2
CASE 3
21 in. Shaft
18 in. Shaft
Shaft Simply Supported at Engine Coupling
Condition 1 Plummer Blocks arranged as in Fig. 1
2 1st Plummer Block moved Forward 28½ in.
3 " " " " " 57 in.

Fig. 3—Bearing loads assuming 2nd plummer block unable to sustain negative loads.

ler alone was 1,150 lb./in.^{2} and at 90 r.p.m., the ship's operating speed, it was found that the first-order bending stress was about 3,500 lb./in.^{2} in the light condition and about 1,500 lb./in.^{2} in the loaded condition. The stress arising from the hydradynamic forces augmented the stress due to the weight of the propeller when the ship was in the light condition, and when the ship was loaded the weight of the propeller tended to neutralize the stress arising from the hydrodynamic forces.

The phase of the first-order stress was given and from this the vertical and horizontal components can be calculated. On the basis of the supposition of a symmetrical wake it may be inferred from the results given for the ship in the light condition, that at the operating speed, the vertical couple due to the thrust is the same as if the propeller was moved some 38 inches further aft and the horizontal force to starboard due to the torque is some 55 per cent of the weight of the propeller.

For this condition of loading the vertical couple and the horizontal force have been plotted against propeller speed and the results lie roughly on a straight line through the origin.

EFFECT OF BLADE FREQUENCY AND HIGHER COMPONENTS OF HYDRODYNAMIC FORCES

The magnitudes of these components are influenced greatly by the shape of the afterbody of the ship and are generally greater for V-shaped than for U-shaped afterbodies. The importance of these components will also depend on whether their effects are magnified by resonance with a natural frequency of lateral vibration of the shafting.

It would appear that two conditions can arise in which the natural frequency of lateral vibration is reduced below normal. These are condition (1) when the ship is in the light condition and the wear-down of the stern bush is small and consequently the loading of the first plummer block is very small or negative, and condition (2) when the wear-down of the stern bush is so great that its loading is small and when the shaft may not be in contact with the second plummer block. Under these conditions the effect of the higher components of the hydrodynamic force in producing lateral vibration and bending stresses in the shafting, may be considerably increased.

The effects of condition (1) may be alleviated by adopting a small clearance in the aftermost plummer block and in this connection it should be noted that a clearance of only 0.010 inches was adopted in the aftermost plummer block of the 17,000-ton tanker, but in the ring-lubricated bearing of the T2 tanker, the clearance is probably much greater. The second plummer block is usually metalled on the lower half only and it appears that little advantage would be gained in departing from this practice in order to reduce effects of condition (2) because it will be seen from Fig. 2 that if the second plummer block were a small clearance bearing the wear-down necessary to reduce loading of the stern bush to zero and would be reduced.

ALLOWABLE WEAR-DOWN OF STERN BUSH

It is possible, from the results given in Fig. 3, to reach some tentative conclusions regarding the allowable wear-down of the stern bush. If this is limited by the loading of the first plummer block, it is of interest to note from Fig. 3 that, if the allowable wear-down is 0.2 in. for the 21-in. shaft in case 1, it will be 0.275 for the 21-in. shaft in case 2 and 0.35 in. for the 21-in. shaft in case 3. If limited by the stress in the shaft, the bending stress at the first plummer block for a wear-down of 0.2 in. is about 2 tons/in.^{2} for the 21-in. shaft in case 1 and that this is reduced 1.5 tons/in.^{2} if this bearing is moved forward to the case 3 position.

Another limitation may be the bearing pressure on the stern bush, for if this is reduced to a value of the same order as the fluctuating force acting on the propeller due to its motion through the water, the shaft may separate from the bearing. If this is the criterion of maximum allowable weardown thus it will be seen from Fig. 3 that, if this maximum allowable wear-down is 0.2 in. for the 21-in. shaft in case 1, then it will be 0.325 in. in case 2.

Particulars have been obtained of the wear-down of the stern bushes of a number of vessels and it would appear that there is a tendency for the wear-down in Diesel-engined tankers having large-diameter shafts to increase rapidly after a certain amount of initial wear at the usual rate. Also, the time between re-wooding is often less than that in ships with machinery amidships in which the shafting is of smaller diameter.

EFFECTIVE UTILIZATION OF MATERIAL

ACKNOWLEDGMENT

This is a condensed version of a paper presented by Mr. Frank Nixon, Assistant General Manager for new manufacturing processes, Rolls-Royce Ltd., before the Institution of Production Engineers in Derby, on 14 December 1953. The article, which is concerned with material utilization in prime movers, was published in the 12 and 19 March 1954 editions of *The Engineer*.

Before going on to consider the more fundamental issues, it will be interesting to obtain a rough idea of some typical figures of material utilization which are being achieved.

After physical properties and general suitability for the purpose, availability and market price of materials are the measures applied by the designer and the production engineer in making their choice. Fig. 1 shows diagrammatically the relative costs of the metals used in engineering, in the forms usually employed. These costs can only be approximate, since they vary according to quantity and quality. Leaving aside titanium, it will be seen that the most expensive metals are about sixty times as costly as the cheapest. These costs indicate the overall difficulty of obtaining the ores, of converting them, and manipulating the crude metal into its usable form.

It is not generally appreciated how great are the quantities involved in the production of metals. A blast-furnace producing 1,000 tons of pig iron per day, for example, requires at least 2,000 tons of ore, 800 tons of coke, 500 tons of limestone, and 4,000 tons of air. In earlier days the blast-furnace was sited close to the source of supply, but nowadays the iron ore may have come from Spain or Australia. Similarly with aluminum, the bauxite will probably have been mined in British Guiana and converted in Canada. Eight pounds of bauxite are required to produce 1 pound of bar and, in addition to the thousands of miles of transportation, about eight units of electricity will have been consumed.

The conversion of ingot into usable forms such as bar or sheet involves a mill loss of 40 to 50 per cent. With static castings the yield from the metal melted may vary between 45 and 65 per cent. In drawing bar into wire rod there will have been a loss of about 5 per cent, and a further loss of 5 per cent in drawing the rod down to wire. Although the material cropped from the ingot and machined from the billet, and the runners and risers from castings, will go back into the furnace, this

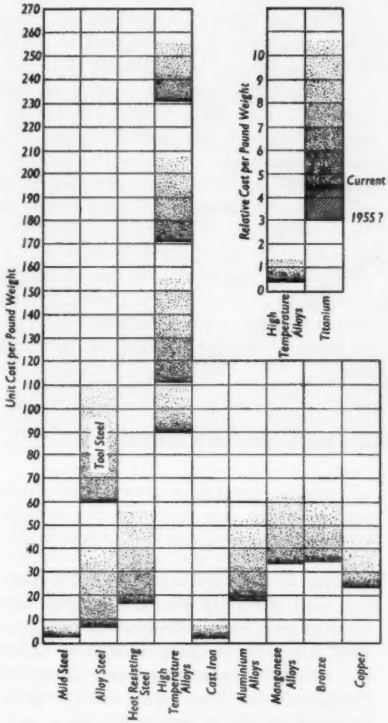

Fig. 1—Relative Costs of Materials

recovery may require more or less refining, depending upon the alloys in question.

Unfortunately, the higher the alloy the more difficult usually is the recovery, and in the case of titanium it is not at the moment possible to reconvert the waste back into the original alloy.

To complete the material picture, Fig. 2 gives an indication of the effect of form on cost. The magnitude of the variation depends largely, of course, upon the alloy and on the quality specified, and it is interesting to note in passing that those forms from which the highest material utilization figures are obtained, i.e., wire, sheet and strip, are the more expensive ones.

Utilization of the material used in the manufacture of products varies enormously. At the one extreme we have the wire cable and the impact extruded tooth-paste tube, with figures of 97 per cent and higher. At the other extreme the figure may be as low as 10 per cent where much machining has had to be carried out. Machinery, which usually comprises an assembly of a greater or lesser number of detail components, will usually have overall values varying from something approaching 40 per cent for

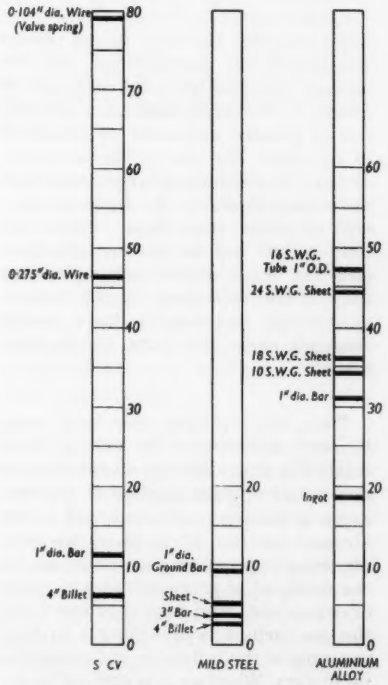

Fig. 2—Cost of Material by Form

the aircraft engine to 60 per cent or more for mass-produced domestic equipment. It is important to realize that a high figure does not necessarily signify an efficient product. In the case of prime movers, for example, it is probable that the highest figures for all time were those of Thomas Newcomen's atmospheric engines.

We have all seen textbook examples of the great savings achieved by changing from a casting to a weldment, from a weldment to a pressing, from a pressing to a forging, from a forging to a casting.

While these figures are undoubtedly true for the examples quoted, they often fail to pay any regard to more than the simple facts of cost of material consumed and labor required, and assume that both alternatives are equally suitable for their purpose, and that production equipment, knowledge, skill and technique already exist and are available. The costs incurred in achieving a saving in material need to take account of these factors, and it will not infrequently be found that a reduction in material utilization may result in a more successful product, i.e. in better effective utilization of material.

FACTORS AFFECTING THE EFFECTIVE UTILIZATION OF MATERIAL

Fundamental Designs.—Many of us will remember the large turnip pocket watches of our grandfathers, and the modern wristwatch is not only a good example of overall material economy, but of greatly increased convenience to the user. So, too, is the miniature camera. In our houses large reductions have been made in the material content of locks (and keys), bolts and bars, which are at least as effective, and far more esthetically pleasing, than those still seen in old houses, and which, incidentally, have hardly changed since the days of the Romans.

Then, too, we have from long usage become accustomed to seeing large relatively slow-moving steam engines and diesel engines applied to stationary and marine work, and only in the air and on the roads have we seen anything approaching an effort to put the material of prime movers to really effective use. And now in these fields the gas turbine is providing a striking example of the influence of fundamental design. Whether it is applied to air, marine, or stationary duties, this type of engine produces power for from one-third to one-seventh the weight of the lightest equivalent power unit.

Thus in the stationary field the Ruston and Hornsby Mark T.A. gas turbine engine has a continuous rating of 1200 b.h.p. for a basic weight of 12,300 lb., which is stated to be one-third the weight of the best equivalent engine. In addition, there are other great savings in the installation, since no heavy foundation is required, and no cooling system, no water softeners, no coal bunkers, and no ash disposal plant.

In the marine field the Rolls-Royce marine gas turbine "RM.60" produces 5,400 b.h.p. for 29,000 lb. weight. As installed, in the "Grey Goose," two of these engines displaced two 4000 b.h.p. steam turbines which were the lightest steam power units of their kind ever produced, but which weighed twice as much. In addition, the "RM. 60" engines require 25 per cent less space and give 30 per cent lower specific fuel consumption.

The "Avon" Mark I engine has a static sea level thrust rating of 6500

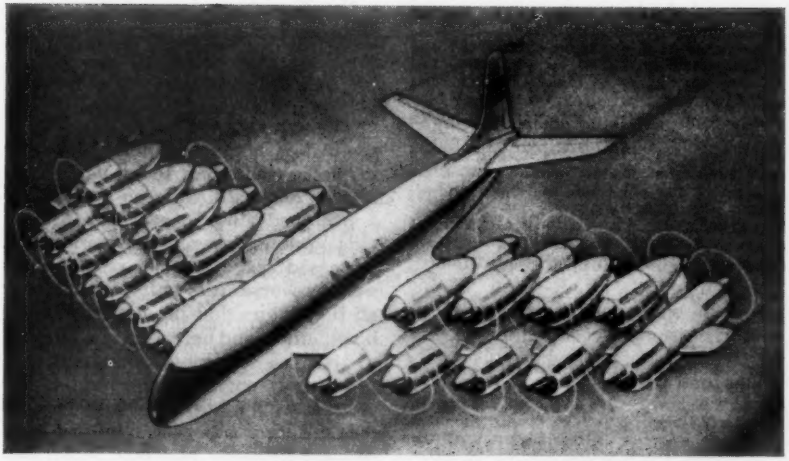

Fig. 3—A Hypothetical "Comet II" if Fitted with "Merlin" Piston Engines

lb. to 7500 lb. depending upon the model. It weighs, complete with its jet pipe, 2710 lb. and it is used to power the "Comet II" aircraft. To propel this aircraft through the air at its continuous cruising speed of 500 m.p.h. at 40,000 ft. requires about 10,000 h.p., or 2500 h.p. from each engine. The highly supercharged "Merlin 724" piston engine weighs dry 2400 lb., but with radiator and coolant, oil cooler, propeller and exhaust system, etc., i.e., as a "going engine," about 3600 lb. At 40,000 ft. it could deliver 450 h.p., or effectively, assuming 80 per cent propeller efficiency, 360 h.p. Admittedly the engine was not designed to operate at this altitude, but it is obvious that the "Avon" engine is making far better use of its material. And if we try to visualize what the "Comet II" would look like if in some nightmare its designer tried to power it with "Merlins," we would get something like the apparition shown in Fig. 3.

At the other end of the horsepower scale we have the small French gas turbine, the Blackburn "Turbomeca Artouste I" and "II," giving continuous powers of 226 b.h.p. and 325 b.h.p. for 183 lb. and 200 lb. weight respectivelv

While in these examples there are great savings as compared with the equivalent power units, there exist also between themselves wide differences of material utilization, as shown bv the weight per horsepower figures. We mav turn for a moment to the reciprocating oil engine and see what might be achieved here by a different basic conception.

If the normallv accepted solutions are examined criticallv. it is difficult to see whv the typical stationary and marine diesel engines are such huge heavv monsters. The reason is most probablv that given by Sir Harrv Ricardo: "One cannot escape the suspicion that the use of very large diesel engines at sea is due, as Sir Alfred Ewing suggested recently, 'rather to the taste and fancy of some dominating personality than to a careful

weighing of arguments such as appeal to engineers.' "

In 1931 and again in 1933 Sir Harry strongly pressed the advantages of using a multiplicity of small high-speed diesel engines instead of the large ones which were, and are still, the prevailing fashion. He showed that the weight per horsepower fell appreciably as engine speed rose and engine size was reduced, and though the cost per ton of the high-speed engine might be treble that of the slower engine, the resulting cost per horsepower of the high-speed engine was only about one-quarter that of the slow one.

Further interesting examples have been given recently of the reductions in weight and real cost of typical motor-cars, amounting to 25 per cent in twenty years. In addition, by the adoption of a V arrangement of cylinders for the engine a 20 per cent saving in weight of power plant is possible.

Detail Design—Within the bounds laid down by the basic design the designer is able to exert a considerable influence upon the product. He will give due weight to a number of considerations having an important bearing upon the way in which the material is used. These include some or all of the following, depending upon the type of thing under consideration.

(a) Purpose and function of product.
(b) Performance.
(c) Cost.
(d) Weight.
(e) Appearance.
(f) Ultimate life.
(g) Running cost.
(h) Overhaul cost.
(i) Style of production.
(j) Availability of desirable materials.
(k) Manufacturing facilities available.

The importance of these factors will vary enormously with the type of product and with the rate and scale of production anticipated for it. For example, a casting left rough will give a higher material utilization figure than a machined-all-over part, but if it entails lower safe working stresses and increased weight the net result might well be worse. It is only by analyzing all the factors that the best result can be obtained, and here a certain amount of give and take by both designer and production engineer is essential for success. This interplay of influences is only effective, however, if the two parties are properly matched. Much has been heard of the American way, where the production engineer has too often overwhelmed the designer, with the result that while there might be overall cheapness and high rate of output, there is inflexibility and a tardiness to take advantage of developments in design thinking. In this country excellent results have been obtained by designers forcing the pace, but this succeeds only when they are matched by production engineers of comparable ability and of sufficient strength to apply the curb when it becomes absolutely necessary.

Mention has already been made of the advantages of small light oil engines. The aircraft engine provides an even more striking example. In order to obtain the highest performance with minimum weight the aircraft engine designer works his engine at the highest temperatures feasible with available materials and he works those materials at the highest possible stresses. This means that expensive special alloys are specified where necessary, and there is no hesitation in calling for what in other fields might seem to be an excessive amount of

machining. Yet the net result is that the prime cost per brake horsepower at continuous rating is appreciably lower for the aircraft engine of the type under review than for any other type of engine in its power class. This is due partly to the quantities produced, but largely to the fact that the increased cost of material and of the greater amount of machining are more than compensated by the increased amount of work done by the material.

Interesting light is thrown on this by a comparison of the "Merlin 724" and the "Avon" Mark I engines. In the bare engines the overall material utilization figures are about the same, but the average cost per pound of the raw material used for the "Avon" is roughly double that of the "Merlin." The manufacturing man-hours per pound are much higher in the case of the "Avon," due to the difficult shapes and still more to the difficult materials employed. Yet the cost per continuous horsepower of the "Avon" Mark I, even at its present early stage of development, is roughly half that of the "Merlin" under equivalent conditions, and this ignores the additional cost of the airscrew, radiators, cowling, etc.

With all this the aircraft engine designer has to keep a careful eye upon the strategic content of his alloys, which may contain high percentages of nickel, chromium, molybdenum, cobalt, etc. It is interesting to note here that in addition to their being technically well ahead, British aircraft gas turbines employ far less of the strategic alloys than do the American engines, and this is another example of effective utilization of material.

An example of this is seen in the case of the "Nene" turbine disc (Fig. 4). This was made originally from a forging weighing 148 lb. in a strategic alloy. By applying air cooling to the disc it was possible to use instead a much lower alloy, and at the same time to reduce the weight of the finished disc by 24 lb. The net saving in cost of the forging was £89. Incidentally, this disc transmits 10,000 h.p.

Where the overriding considerations of performance and reliability permit, the designer can help greatly by making provision for easy replacement of vulnerable parts. By keeping the number of different parts to a minimum there are savings at every stage, but in addition there can be, too, an appreciable saving in material, through reduced discards as well as reduced holdings of raw material and spare stocks.

Whatever the product, the designer can play a great part by refraining from calling unnecessarily for materials which are difficult to obtain, for

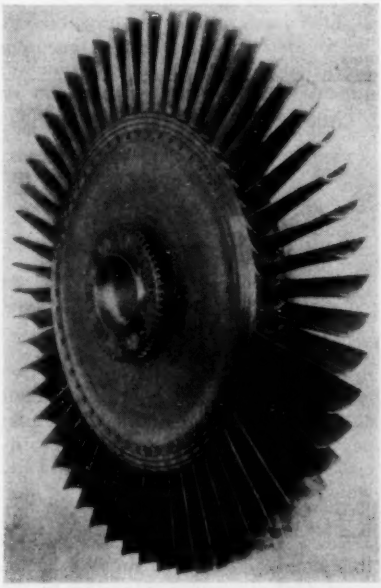

Fig. 4—"Nene" Turbine Disc

tolerances requiring new machines or inspection equipment or leading to a higher rejection rate, for modifications involving wastage of material and jigs and fixtures and tools.

Development—The development department is of particular importance in the case of machines and prime movers. In these fields the function of the development engineer is to test the product to discover its weakness and by eliminating them to increase its reliability and its life and its specific performance.

The prototype of development engineers was Richard Trevithick, who in 1804 broke away from the tradition of the heavy and cumbrous atmospheric engines of Boulton and Watt and introduced high-pressure steam. In one leap he multiplied the power output of a given size of engines several times, and not only made railway locomotion possible, but pioneered it as well. This work caused about as big a stir as that of the gas turbine engine today.

Returning to the aircraft engine, the overhaul life of the civil "Merlin 724" engine was raised by development from 600 hours to 1250 hours, for an increase in weight of only 70 lb. and only a small increase in cost. This engine is one of the latest of a long line of basically similar ones of 27 litres capacity which started in the last war as a 1000 b.h.p. engine and finished at nearly 2000 b.h.p. again largely through development.

Another good example of development is found in the Nimonic alloys which are used for turbine blades. Table I shows how during the past few years the strength at temperature has

Table I.—*Development in Nimonic Alloys*

Alloy	Temperature for fracture in 100 hours at x tons per square inch	Corresponding increase in thermal efficiency	Corresponding increase in thrust per pound of air consumed
	Deg. Cent.	Per cent	Per cent
80A	880	—	—
90	910	2.6	8
95	940	4	16

been increased to give an effective rise in operating temperature of about 60 deg. Cent., which enables the thrust per pound of air consumed to be increased by 16 per cent for the same weight of engine.

Research—It is unfortunate that, in this country at least, there exists a good deal of misunderstanding of the true meaning and function of research, as much amongst research workers themselves as in the minds of practical engineers. This has led to confusion and overlapping, doubt and suspicion, and some lack of cooperation.

Some researchers have tended to weaken the faith of engineers by trying to provide quick answers to practical problems when they would have been better occupied in seeking fun-

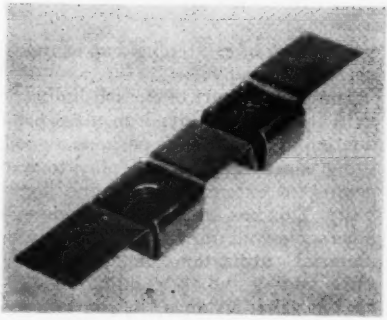

Fig. 5—Automobile Body Cage Nuts

damental solutions. It is not appreciated as it should be how narrow is in fact the gap between the production engineer and the fundamental research worker, and efforts to fill this gap by so-called researchers is tending to result in a good deal of redundancy.

Much of the most successful research has been carried out by men of practical outlook. It is interesting to look for a moment at the work of the past few decades, which has led to enormous improvements in material utilization.

For instance, it is about 100 years since the phenomenon of fatigue was first recognized by Robert Stephenson and others.

Then, in 1871, Wohler published his work on endurance tests under reversals of stress. But it required the impetus of the first world war to bring about an intensification of research effort, and the practical application of it to design. Other allied researches were made on the stress concentration due to sharp corners and oil holes, and on the effects of surface finish, notably by Professor Coker, Dr. A. A. Griffith and others. Most of this work was inspired by the needs of the aircraft engine, and a good deal of it was in fact carried out under the auspices of the Aeronautical Research Committee. If we look back at textbooks of engineering design of thirty to forty years ago there is no mention at all of the importance of adequate fillet radii, good surface finish, and freedom from cracks, and illustrations of engines show a frightening lack of any sort of radius at shoulders in keyways, etc. In fact, even more recently during his apprenticeship, the writer was once taken seriously to task by a foreman because he had not removed the radii from the root of a keyway, and produced a fitting key with dead sharp edges!

This work, by enabling the designer to work with a more accurate knowledge of stresses and hence with a lower factor of safety, has led to a lightening of structures generally with, in the aggregate, an enormous saving in material.

Of even greater importance has been the very great increase in reliability which has come about in many fields—machine tools, presses, motor-cars, railway wagons, aircraft engines, and so on, which indirectly has meant again better material utilization.

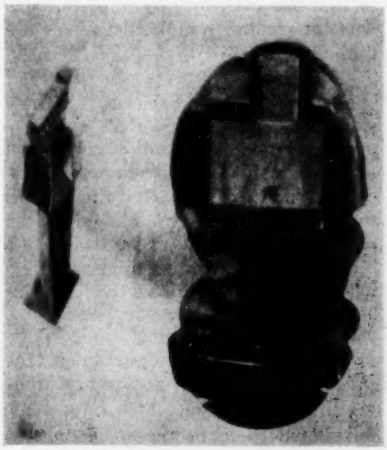

Fig. 6—"Dart" Turbine Blade

MANUFACTURE

Here we come to the section of primary interest to the production engineer. Every aspect of production management and engineering is concerned, and while these cannot have the same influence as design upon material utilization, they play a very big part in the ultimate cost of the product. While the high performance, the light weight, and the reliability of the "Avon" engine, for example, are due in the main to the effects of the design, development, and research departments, the relatively low cost is due in the main to the manufacturing side, which has made a most important contribution to the other aspects too, by finding ways of forming and fabricating materials normally considered to be "impossible." Although the designer may be setting the pace, it is the production engineer who maintains it, as much today as 180 years ago, when John Wilkinson's boring mill allowed steam engine development to go forward. It may be remembered that he bored a 50-in. diameter cylinder to a tolerance equal to the thickness of an old shilling, and later improved his technique so that the tolerance on a 72-in. bore was not greater than the thickness of a thin sixpence.

Rate and Scale of Production—Considerable responsibility rests upon the production engineer and management alike, to ensure that the choice of machinery and methods, and the type of tooling, are properly matched to the scale of production. There has of late been a good deal of misunderstanding here, due in the main to a too loose use of the terms "increased production," "large-scale production," and "mass production." As a consequence, the special techniques of design and tooling and production which have been developed to meet the needs of the motor-car and ancillary industries, for example, are too often held up as models for all to copy.

The greater part of British industry is in fact not employed on mass production at all, which is perhaps a good thing, since it gives full play to our genius for extemporization and flexibility. This has an important and perhaps somewhat unexpected effect upon material utilization in minimizing scrap and wasted effort due to modifications. For instance, in the case of large bomber aircraft, during the war, the productive man-hours per pound of aircraft were almost identical for similar British and American machines. As modifications became necessary to overcome defects, or to meet tactical or strategic needs, they were introduced quickly and smoothly into the British aircraft, without interrupting the production flow or reducing the output. In the States the planned "mass production" lines were so rigid that the factories had to go on producing obsolete aircraft which were then shipped hundreds of miles away to modification centers, where the new parts were fitted and the old thrown away.

At the opposite end of the scale a free and unfettered outlook, capable of turning away from the orthodox and getting right down to fundamentals, can save enormously by resisting the temptation to spend unnecessarily on equipment of high capacity and to use common sense instead. The double cage nut shown in Fig. 5 is a good example. Planned along textbook lines, this item, which is required in tens of thousands, would be made from steel strip, on a battery of roll feed and dial feed presses costing about £3600, with tools costing about £500, and at a rate of, say, forty per minute. It is actually produced at the same rate, on a battery of four fly presses costing, say £140,

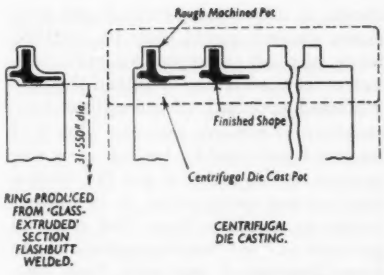

Fig. 7—Extruded and Cast Rings

with tools costing about £30. By using offcuts, which would be impossible on the automatic machines, the selling price is considerably below that of the fully-tooled job. Perhaps the greatest scope for improved flexibility is in the sheet metal field, where, following the lead of the motor body manufacturers, high tooling costs have come to be regarded as commonplace, and in consequence inevitable and acceptable. The possibilities here will be dealt with later.

In this connection a speech by Mr. Gordon McGregor, president of Trans Canada Airlines, at the recent dinner of the Society of British Aircraft Constructors, is worth quoting. Dealing with the success of the British aircraft industry in overseas markets for civil aircraft, he said: "Manpower is such an expensive commodity in the United States that it is becoming increasingly necessary to go to any length to conserve it . . . This condition is driving the American manufacturer into fantastically large investments in tooling. Where vast production quantities are involved no harm is done . . . (but) these advantages unhappily vanish where the production of large civil aircraft is involved. The total number of any one type is unlikely to exceed 200 or 300; yet, having been driven into a massive investment in tooling, the manufacturer finds it economically difficult to abandon a design in favor of one more advanced . . . On the other hand, the lower cost of manpower in this country makes possible its greater use, with a consequently smaller investment in the tooling specific to any one aircraft type. A manufacturer in Great Britain could undertake the production of a comparatively small number of any one type, without risking the financial loss of a large amount of scrapped tooling."

It is as well to bear these remarks in mind when one is approached by an American salesman trying to recover the costs of developing his wonder machine by selling some abroad.

Choice of Method—No manufacturing process which offers an advantage in any way can be ignored, and in consequence we find that most available processes are employed to a greater or lesser degree.

We find then, in the aircraft engine, forgings and drop stampings in high-tensile and in high-temperature alloy steels machined all over; precision die-forged blades in a wide variety of materials, machined only on the roots; sand castings, die castings, centri-castings, centri - spinnings, shell mouldings, and precision castings in light alloy, iron, steel, and high-temperature alloys; hot extrusion, impact extrusions, pressings, spinnings, and fabrications in light alloy, alloy steel, stainless steel and high-temperature alloys; brazings by torch, salt bath, induction and furnace in a variety of alloys; weldments by arc, shielded inert gas metallic arc, torch, spot, stitch, seam and flash butt.

Such a great diversity is only possible in a fairly large organization employed on a high-quality product where performance is the primary

Fig. 8—Compressor Rotor and Blank for the "Derwent" Engine

concern. The task of the production engineer is to insure that each process is employed efficiently, in the right application, and on the appropriate scale. In fact, the wide variety does not so much entail expensive equipment as a broad knowledge of skills and techniques. The claims put forward for any new process are viewed most critically, and in many cases the chief value of a new process has been to provide a spur to a fresh analysis of the shortcomings of the existing method.

Perhaps because the aircraft engine manufacturers has had to become a master of all trades he is well qualified to comment on the questions which are so much occupying management and production engineers today. Spurred on by the needs of the engine, he has in several vital instances been compelled to adopt processes which have normally been operated by specialist trades and to develop them, in an extremely short space of time, to a pitch which the expert has stated was impossible. This has been achieved by a refusal to accept statements without proof, by a straightforward approach to the problem.

In fairness to some members of the specialist trades, it must be said that in the first instance the new developments, as of precision forging and precision casting, could only be justified when applied to expensive materials, but even then it has required the uninhibited approach of the enthusiastic amateur to achieve success. This will be best illustrated by taking a few examples, and in order to put the matter into correct perspective it is appropriate to mention here that over 30 per cent of the finished engine is made from forgings, 5 per cent from bar, over 40 per cent from castings, and 10 per cent from sheet and tube. The overall utilization figures average 22 per cent for forgings, 44 per cent for castings, and 50 per cent for sheet metal parts.

Forging—The chief influence of the aircraft engine industry here has been due to its insistence upon absolute cleanliness of the metal, accurately controlled forging to give the most appropriate grain flow, and withal the development of materials of ever-increasing strength, which has intensified considerably the task. For instance, ultimate strengths of 65-75 tons per square inch for nitriding crankshaft steels, 100 tons per square inch for case-hardening steels for radial engine connecting rods, and 85 tons per square inch for case-hardening gear steels, were normal for the engines of the last war. Machining and finishing all over were, of course, essential, as much to provide the highest possible resistance to fatigue as to reduce weight to a minimum. For example, the ("Bristol") radial engine master rod weighs 9¼ lb. and has been machined from a forging in 100-ton case-hardening steel weighing 42 lb., a material utilization of 22 per cent. This figure needs to be regarded in light of the fact that the rod is transmitting over 1000 b.h.p.

Fig 8 shows the light alloy forging and the finished compressor rotor of

the "Derwent" engine. The material utilization is 48 per cent. In the axial engine the turbine and compressor blades present a special set of problems, due to their shape and to the materials from which they are made. The difficulties of producing accurately thin aerofoil sections, having varying degrees of camber and twist according to the still limited but growing experience of design and performance, in light alloys, stainless steels and high-temperature alloys, have naturally led to a number of different solutions, both in this country and in the States.

With blade shapes and methods still in a somewhat fluid state it is perhaps a little too early to be definite about the ideal solution, and since there is in addition a wide variety of design practice in the form of root fixing, it is possible that more than one method may persist. In the author's personal opinion, however, there is little doubt that precision forging of the aerofoil will always play a big part.

This is one of the cases where the engine manufacturer has had to master a trade and point the way. This is exemplified by the turbine blade of the "Dart" engine (Fig. 6), which is forged to size on the aerofoil and on the platforms, so that these areas require no machining other than the radiusing of the leading and trailing edges after the flash had been clipped off.

Precision forging of less difficult shapes and in less difficult materials and to somewhat wider tolerances is, of course, well established. Losses occur between bar and forging due to the flash, scale, tonghold, test piece in the case of aircraft engine parts, and parting or shearing. These may amount to 30 to 40 per cent according to shape.

Another interesting example of progress in the wrought materials field is shown in the adoption of the Ugine Sejournet process for the extrusion of sections in stainless and alloy steels. The gas turbine engine, being essentially cylindrical, employs a fair number of circular flanges, which are welded on to casings. These flanges have been turned from cylindrical forged or cast rings with material utilization, of fairly expensive metal of about 22 per cent. By making rings of extruded section, coiled and flash-butt welded, the overall utilization has been increased to about 36 per cent and there has been a reduction in overall cost (Fig. 7).

The extrusion process, too, holds out considerable promise of greatly improved yields from ingot to usable form, a development of particular value in the case of the expensive strategic materials.

Mention must be made, too, of rolled and drawn shapes, where the utilization can be high. Aerofoil sections can be rolled in lengths of stainless steel, with a loss of only 4 per cent from bar to blade section. Complex shapes can be cold rolled to a high degree of accuracy, with a loss of from 3 to 7 per cent. The only additional loss in applying these forms to compressor blades, gun trigger mechanisms and the like is that incurred during parting off.

Fig. 9—Recent Examples of Castings in Steel

Casting—That castings are not in general use for highly stressed moving parts is due in the main to a widespread distrust which can usually be traced back to some unfortunate experience, such as that never-to-be-forgotten occasion when, as a child, the author dropped his new toy revolver and the casting shattered. Castings cannot always be produced to the dimensional accuracy and thinness which is dictated by the insistence upon lightness. They find their widest application, therefore, in light alloy static castings, where the effect of dimensional errors is not so great; to iron castings which can be machined all over; and to precision castings in high-temperature alloys for smaller static components, such as nozzle guide vanes.

The economic advantages of being able to use as-cast parts for other components than these are so great that it is not surprising to see in the foundry industry today greater activity than for a long time past. We have seen during recent years the development of lost wax (e.g. Austenal and Trucast) and frozen mercury investment casting, shell molding, the Shaw process, plaster molding, permanent mold casting of ferrous alloys, and so on. In the main, however, these have been mold making rather than founding methods, and while they have undoubtedly led to improvements in accuracy and cost, improvements in the quality of the castings have in most cases been incidental. Fortunately the need for fundamental work on the metallurgical and founding sides is being appreciated more and more widely, and it is pleasing to note that considerable improvements have already been obtained, whilst others are pending, both as regards the accuracy of bigger castings, and the physical properties and reliability of smaller ones.

The argument usually adduced against castings is that they are unreliable because of the difficulty of insuring freedom from undesirable inclusions, porosity due to shrinkage and gas, coarse structure, hard and brittle spots, shrinkage cracks, and so on. One of the main functions of forging is in fact to minimize the effect of such defects in the as-cast ingot.

By systematic attack upon the basic causes of these defects considerable advances are being made. The Qualcast permanent mold process, for example, is producing castings completely free from porosity, with fine grain and with a mirror finish, if required. Cast crankshafts for motor-car engines and compressors, which were first mooted in 1912, have been commonplace for the past fifteen years or so as sand castings by the same company, by Jessops and others. The Ford Motor Company has cast its crankshafts for years, more recently by the Shell process, and camshafts and valves as well.

Porosity and control of grain size are being tackled in a variety of ways, as instanced by the cast milling cutters of B.S.A., whose cast steel forging dies are also coming into general use. Vacuum casting, controlled rate of freezing, as by the Parlanti and other methods, and the development of high-duty heat-resisting alloys specially adapted for casting are all playing their part. In the United States cast turbing blades are being used in some aircraft engines.

Where operating temperatures preclude the use of light alloys, iron and nickel-chrome steel castings are used, and are machined all over to obtain consistent thicknesses. Where it is not possible, by reason of the shape, to machine all over, recourse may be had to a composite construction. It is en-

couraging that in one foundry at least, making static castings, tolerances of ±0.005 in. on as-cast diameters of 30 in. or more are within sight of achievement. Further development is urgently needed to enable castings to be produced to the desired thickness without machining. It is a sobering thought that this will only bring us to the stage reached by the ancient Greeks, who were able to cast, by the lost-wax process, bronze statues, one of which was 6 ft. high, weighing only 100 lb. and averaging less than 0.100 in. thickness. Earlier Egyptian castings were even thinner.

In castings such as those just postulated there is little doubt that the new spheroidal graphite cast iron will play a big part. With up to double the strength of ordinary cast iron, and much greater ductility and greater stiffness, it will help a great deal to keep material weight down.

There has during the past few years been a tendency to replace cast structures by weldments. Cases have been made out showing appreciable savings in weight and reduced cost due to no pattern being required. These are perfectly true when comparing steel with cast iron, and when considering one-offs, but Fig. 9 shows that cast steel structural members are staging a comeback, in this case in a marine application, and where even quite small quantities are required the cost of the pattern is very soon paid for by the saving in time in cutting out the steel plate and jigging and welding it up and inspecting the welds.

Where shapes are difficult to machine, as in nozzle guide vanes shown in Fig. 10, the most expensive casting method—lost wax investment casting, can be justified. These components are cast to size on the aerofoil and the platform. The small size of the cored holes should be noticed, and in passing it may be mentioned that these are not by any means the longest cores of their size which are being produced.

Bidding fair to produce castings of comparable accuracy is the shell process. As this requires a metal pattern its use cannot always be justified, and there is a limitation imposed, too, by the complexity of the casting. Where profiles can be left as-cast which previously had to be milled, however, great savings both in metal and machining time are possible. Fig. 11 shows cross-sections of a casting produced originally in sand and weighing 107 lb. as cast, 11½ lb. finish machined. The first economy was to have the rough machining done by the foundry, since this put a higher value on the scrap than when it was returned from the customer. The final version,

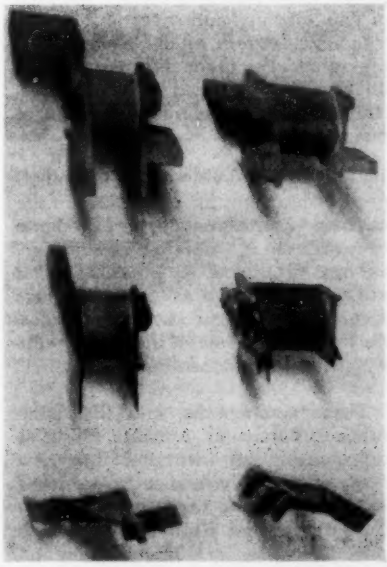

Fig. 10—Nozzle Guide Vanes

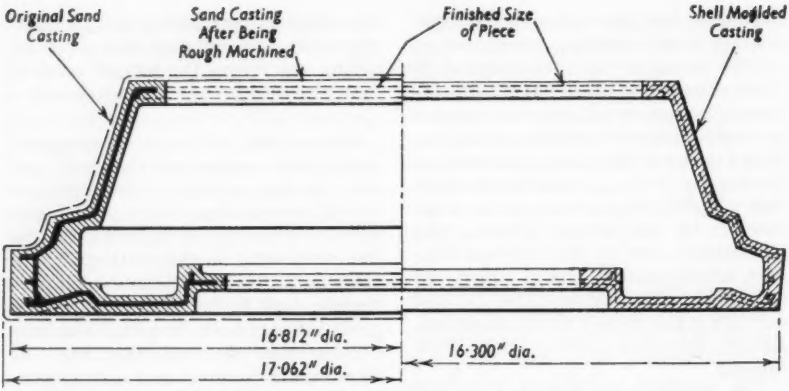

Fig. 11—Comparison of Components when Cast in Sand and when Shell Moulded

by shell molding, weighs 38 lb. saves nearly £14 worth of material and much machining.

A modern casting development which should help to reduce the cost of bar, forgings and sheet is the continuous casting of billets. By avoiding piping and the other defects of ingots an economy of about 30 per cent is claimed, plus the elimination of ingot molds.

Fabrication—Fabricated sheet metal parts occupy an important place in the aircraft gas turbine engine for flame tubes, discharge nozzles, air casings, exhaust units, and jet pipes. Material utilizations as high as 56 per cent are obtained with these components, and they play a big part in the low specific weight of the gas turbine engine.

These components, and the flame tubes in particular, are interesting as representing an incursion into new fields of accuracy in sheet metal parts of their size. The flame tube is made from light-gage Nimonic sheet, and since the efficiency of combustion and the life of the flame tube itself depend upon the accurate guiding and metering of a stream of air flowing through it at about 20 tons per hour, along carefully predetermined paths, it must be made extremely accurately. Since it is required in not very large quantities as compared with what is usual in the precision sheet metal field, and since the material is extremely difficult to form, requiring several anneals and draws in easy stages for many of the components, it has presented new problems of tooling and manufacture.

The pressings must be free from internal stress, the welds must be of first quality, and all free edges, as at joints and round the holes, must be carefully radiused and polished. The composite construction, too, entails great accuracy of trimming and locating to insure that joints fit properly and that the overall tolerances on the assembly shall be met. Wherever possible, in order to improve material utilization and to reduce the number of tools required, cylindrical components are made by wrapping sheet, welding and sizing.

The subdivision of the costs of material and the different manufacturing operations is rather revealing, as Shown in Table II.

TABLE II—*Breakdown of Flame Tube Manufacture*

	Per cent of total cost
1. Raw material	45.5
2. Pressing, forming, and shaping	6.7
3. Deburring, radiusing and flash removal	14.2
4. Preparation for welding, i. e. cleaning, jigging and tacking	9.0
5. Welding and brazing	8.3
6. Machining	12.0
7. Miscellaneous handwork, etc.	4.3
Total cost	100.0

The small part played by pressing and forming, and the relative importance of machining, locating, welding and finishing are particularly noteworthy. This analysis is useful as indicating the directions in which efforts should be directed to reduce costs. One thing is immediately apparent: the cost of multiplicity of constituent components as affecting machining, locating and welding. This is in fact the biggest drawback of fabricated construction, and due account needs also to be taken of the cost of tooling, which will be roughly proportional to the number of constituent components.

As normally practiced, the multiple sets of tools required for pressing Nimonic components can become an expensive item. In this case expense means not only increased cost per component, but also greatly reduced flexibility and long delays in starting production or in introducing modifications. A considerable effort is being made therefore to reduce the number of tools required by work along a number of lines. One process, known as Dyzacking, is able, by using a proportion of skill along with the necessary tools, to start production of components for a small fraction of the tool cost and several weeks ahead of the normal method. It is still uncertain to what extent this method will be able to compete with the fully tooled method for really large quantities, but for orders of the appropriate size and for a quick getaway it represents a considerable step in the right direction.

Several other methods are being developed, aiming at similar flexibility of output and more universal equipment, so that tooling costs will fall and speed of introduction rise.

Where a complex casting is replaced by a composite fabrication there will in general be an increase in cost, owing to the amount of tooling, accurate trimming, machining and handwork to control and correct welding distortion. In special cases, however, fabrication may be cheaper than a cast construction.

This is perhaps the place to mention the latest competitor of sheet metal—the plastic laminate. Reinforced with glass or other substance, plastics are providing a serious threat to steel for motor-car bodies, and weight savings of up to 45 per cent in body panels and hard tops are being obtained. With some of the latest reinforcing materials (not glass) costs 15 per cent lower than those of orthodox steel parts are claimed.

This same company again has achieved important weight and cost savings with its Marston Flexelite fuel tanks for aircraft. Made from nylon material of handkerchief thickness, impregnated with hycar, these tanks

are crash-proof, and after allowing for the additional structure to contain them, they weigh up to 33 per cent less and cost up to 22 per cent less than metal tanks.

Manufacturing Efficiency—It goes without saying that efficient shop management and planning play a big part in the ultimate cost of an article, but it is perhaps not generally realized how great in fact can be this influence, and how relatively easy it should be to effect really big improvements to the benefit of all of us.

Fig. 12 shows, on a comparative basis, the costs of a number of components, produced by similar methods and at comparable rates by different firms. This information has been obtained from a number of sources in a variety of industries, and amongst the components are machined parts, forgings, precision forgings and castings, pressings and fabrications.

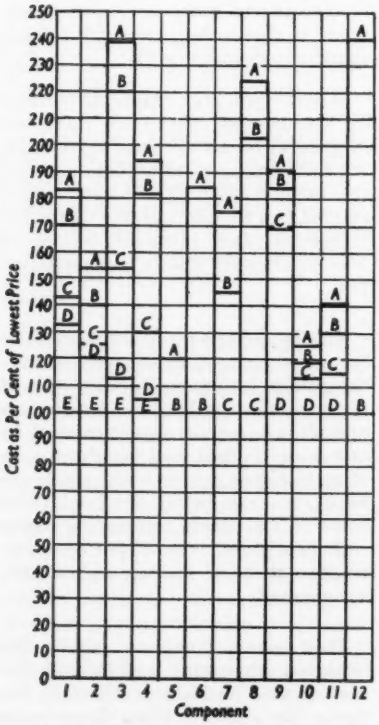

Fig. 12—Comparison of Manufacturing Costs

Great care has been taken to insure the accuracy and comparativeness of the figures. They take no account of capital expenditure on plant and equipment nor of the cost of tooling for the particular components, so that they are in fact a good measure of the production efficiency of the firms concerned. Care has been taken to insure that the figures are those which apply after initial teething troubles have been overcome and that they hold for comparable quanities.

Through the co-operation of some of those concerned it has been possible to discover a few of the factors responsible. In nearly every case there has been an acceptance of the existing state of affairs as unavoidable, while just plain bad costing has been the next common factor. A great value of the investigation has been the discovery of differing detail practices which have had a considerable influence upon overall material costs and labor times.

Amongst these differences were found in one case a material utilization of 41 per cent, as compared with 55 per cent in the best case, and accounting for £4 in the cost of a £20 component; in another, a rejection rate double that of the best case, due to the unexpected effect of an "economy" measure; in another, an excessive amount of corrective work which was eliminated by a simple change of method; in yet another, excessive scrap due to inefficient inspection. Differences in incentive methods, and in such elementals as effective shop loading, have

had a big influence upon manufacturing times, so much so that differences of 100 per cent have been seen as applying to identical components made by identical methods. It is perhaps not without significance that the best results have in some cases been obtained where there has been least expenditure on tooling.

One overriding difference which is apparent between the better and the more costly concerns is in the outlook of the personnel involved. Those producing the best results have in common a simple, direct and confident approach to the job. This has led to a questioning of the methods and results achieved at each stage, and a refusal to accept the obvious until it has been checked and confirmed. By this means it has been found relatively easy to avoid or eliminate inefficiencies which have had a big bearing on the cost of the component.

Reclamation and Scrap — With three-quarters or more of the original ingot metal being discarded as croppings or mill loss or machinings or spoilt work there is a fruitful field for recovery. This scrap metal, plus that which is collected as salvage now bulks largely in our overall metals economy. For instance, up to 30 per cent of our tin, 35 per cent of our copper, and 40 per cent of our lead comes from scrap. An appreciable portion of this reconverted scrap comes from salvage, which is becoming increasingly important. Many thousands of tons of aluminum in the form of milk bottle tops, chocolate wrappings, and so on, become waste every year. Collections are made from municipal authorities, and up to 4 tons of ferrous scrap per 1,000 of population is gathered in. In addition, about half a million tons of ferrous scrap is imported every year.

In the case of alloys their cost insures a more careful and rapid return of waste. That occurring in the cogging or rolling mill and the foundry, for example, finds its way back to the furnace pretty quickly. Careful segregation eases the problem of re-melting into the desired alloys, but nevertheless a good deal of work has had to be carried out and much care is necessary to insure consistency and accuracy of the alloys produced. This is even more difficult with machinings, where cutting oils, dirt and foreign matter may have been introduced.

It is especially noteworthy then to see that it has been established recently that machining scrap of high alloy heat-resisting steels can be reclaimed most economically and even the highly critical Nimonic alloys can now be reproduced safely from their machining scrap. This is indeed an achievement, since the slightest trace of adulterant such as lead can completely ruin a melt. Even if this reclamation were uneconomical financially, it could in time of emergency become absolutely vital. Scrap recovery of this kind has been going on for a long time.

One of the big advantages of the discovery of the casting process, in the Bronze Age, was that tools and weapons which had broken or worn could be recast as good as new, whereas earlier hand forgings could not be reclaimed.

Repair and Maintenance—Because of their inherently high duty, aircraft engines are usually given short overhaul lives when they are first introduced into service. At the end of the specified time, which during the war was 300 to 400 hours for piston engines, the engines are withdrawn for a complete overhaul, which restores them to their full original effectiveness and reliability, for a fraction of their

prime cost. It is the constant aim to increase the overhaul life and to reduce the cost of parts needing replacement. In the case of the "Avon" Mark I engine the results have been most gratifying for such an early stage of development. During the war, despite the heavy losses in combat, the overall value of the original effort put into building "Merlin" engines, as measured by the total engine flying hours, was doubled by repair.

DERIVATION OF A STABILITY PLOTTING BOARD

LIEUTENANT ABNER SHERMAN SMILES, USNR

THE AUTHOR

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INTRODUCTION

The estimation of the stability picture of a ship in the hypothetical damage condition, or in the assumed extreme loaded conditions has been a time consuming effort on the part of Damage Control Officers and their assistants. Unless the officers involved have some insight into draftsmanship and curve plotting, the task of deriving the Statical Stability Curves for a ship in various conditions of loading would have a tendency to be neglected. Then the subsequent approximations of stability for certain conditions of existing load (whether this is due to damage, abnormal loading, etc.) will not be on hand to enable a general apprehension of ship's characteristics to the Commanding Officer. In this regard, a resume of existing methods of plotting statical stability curves will be unfolded.

At present in order to estimate the general stability picture, one needs to develop the Statical Stability Curves for the given ship at the given Displacement. This is developed from the Cross Curves of Stability of the ship from the respective Inclining Experiment Booklet. This Statical Stability Curve is correct, i.e. GZ (Righting Arm) values are valid, if center of gravity of ship is located at point A (assumed center of gravity, by the Designing Naval Architect).

We have seen that in order to correct the Statical Stability Curves from the center of gravity existing due to the shift upwards (or downwards) from the assumed center of gravity of the Naval Architects to the prevailing G (possibly the Virtual G of ship), it is necessary to consider the various conditions effecting the shift from assumed A to the following:

from A to G—shift from assumed center of gravity of the Designer's to

actual center of gravity of ship before damage, weight changes, etc.

from G to G_1—shift from actual G of ship before weight changes to the actual G_1 after weight additions (or removals).

from G_1 to G_V—shift from actual G_1 of ship after damage or new condition to the Virtual center of gravity of ship. This is due to the virtual rise in G due to Free Surface Effect of additional loose water, Free Communication Effect, and Free Surface Effect of Ship's Tanks corrected for the new displacement.

It has been found that to correct the Uncorrected Statical Stability Curve (i.e., it is correct if G of ship was at point A), it is necessary to add or deduct (usually the case) the value of $AG_V \sin \theta$ for all values of θ (various angles during the roll of ship). This is accomplished by superimposing a sine curve, whose amplitute is AG_V and phase angle ψ is 0°; (a sine curve beginning at 0° and reaching a maximum value of AG_V at 90°) on the same grid as the Uncorrected Statical Stability Curve derived from the Cross Curves of Stability. Then the graphical difference between the two curves is the Remaining (Residual) Statical Stability due to shifts of G of ship upwards (or downwards).

Furthermore, to correct this Remaining Statical Stability Curve for the off-center shift of G of ship, it has been found that the loss in GZ (Righting Arms) at each angle during the period of roll is equal to $G_1 G_2$ (off center shift of G of ship) multiplied by $\cos \theta$, i.e., $(G_1 G_2) \cos \theta$. This is accomplished graphically by superimposing a cosine curve (whose amplitude is $G_1 G_2$ and phase angle $\psi = 0$, i.e., at 0°, the cosine function is at a maximum value of $G_1 G_2$; and at 90° the cosine value is 0). The difference between the cosine curve and the remaining curve available after the sine correction, will be the Residual Statical Stability Curvé, corrected for the vertical and horizontal shift of G of ship.

At this moment, it is noted that there are two correcting curves plotted at separate times, deductions (or additions), made twice, which can increase possible error and consume time if the officers involved are not keen and adept draftsmen.

The need to *eliminate* the *use of two curves* for correction and to *decrease the time necessary to plot the Residuary* Statical Stability Curve is apprehended, and with this in mind, the object of this discourse is unfolded. It is to be noted that the job of locating the position of G of ship still remains with us, until such time in future when the KG value of a ship in any situation of load can be ascertained more readily than by present methods. Calculations of KG is simplified by using various values of weight and vertical moments about baseline, which were previously worked out in the Inclining Experiment Booklet, or by a collection of data estimated in advance.

OBJECT

The presentation of this discourse is to promote a *means* in working Statical Stability Problems in order:

1. To decrease the time necessary to plot a correct Statical Stability picture of a ship in various past, existing and intended conditions, without sacrificing the accuracy and the perspective of desired conclusions.

2. To eliminate the plotting of the two correcting curves, i.e., Sine and Cosine Correction Curves, so as to reduce the error due to numerical calculation, graphical plotting, and graphical reading.

DEFINITION OF TERMS

From the Trigonometry, refer to Fig. 1.

In a right triangle

$$\text{sine of angle} = \frac{\text{side opposite the angle}}{\text{hypotenuse}}$$

i.e., $\sin\theta = \frac{b}{c}$

$$\text{cosine of angle} = \frac{\text{side adjacent to the angle}}{\text{hypotenuse}}$$

i.e., $\cos\theta = \frac{a}{c}$

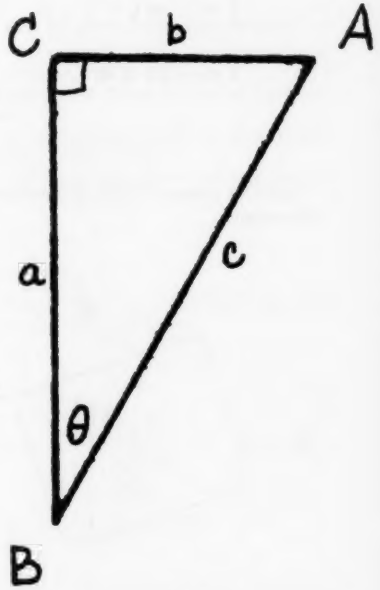

Fig. 1

Law of Pythagoras, i.e., $c^2 = a^2 + b^2$

or $c = \sqrt{a^2 + b^2}$

or c is hypotenuse of a right triangle whose sides are a and b.

Sine Sum of Two Angles

$\sin(A + B) = \sin A \cos B + \cos A \sin B$

A and B can be any angles, i.e., $A = \theta$, $B = \psi$

$\sin(\theta + \psi) = \sin\theta \cos\psi + \cos\theta \sin\psi$

In a sine curve, which varies from 0 at 0° to the full value at 90°, the amplitude of the sine curve is the maximum value; refer Fig. 2.

If the sine curve does not start at 0°, but at another angle, i.e., the sine value at 30° is 0, we say that the phase angle of the sine curve is 30°, for the sine curve has shifted over to 30°; refer to Fig. 3.

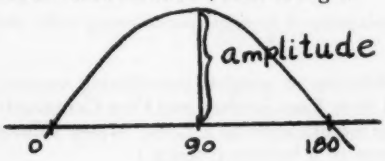

Fig. 2

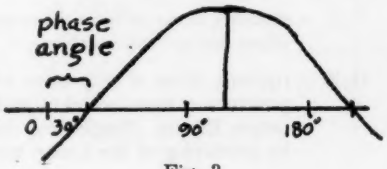

Fig. 3

Note: the plot of a sine curve of sin $(\theta + 30°)$ is described by illustration, Fig. 3. From the algebra

$$\frac{c}{c} = 1; \text{ let } a + b = d$$

$$1\,(a + b) = d; \qquad \frac{c}{c}(a + b) = d; \qquad c\left(\frac{a}{c} + \frac{b}{c}\right) = d;$$

THEORY

In most cases of shift of center of gravity of ship, it is seen that G shifts up and off center.

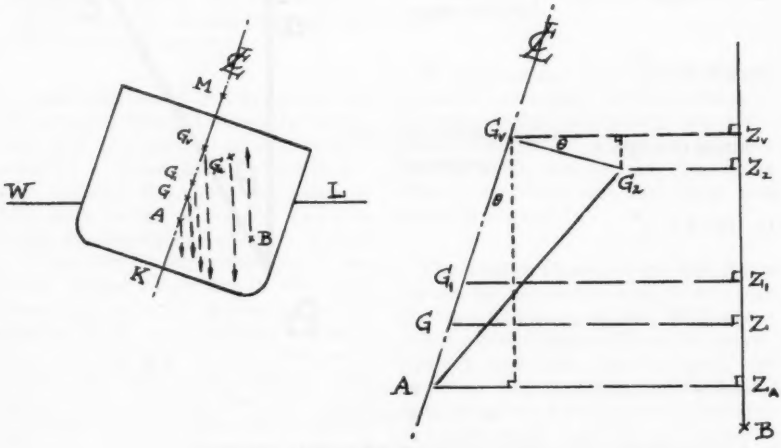

Fig. 4

At any particular instant (i.e. θ during a roll of the ship, the analysis of forces acting were analyzed as follows; refer to Fig. 4:

AZ_a = righting arm of ship with center of gravity located at point A, assumed by Designing Naval Architect—these righting arms are those derived from Cross Curves of Stability.

GZ = righting arms of ship before addition of weights, i.e., condition before changes.

G_1Z_1 = righting arms of ship after additions of weight, considering only the effect due to their locations.

G_VZ_V = righting arms of ship after additions of weights considering vertical positions of these weights, and their Free Surface and Free Communication Effects. (Neglecting the modification to a Loose Water Effects by pocketing of the Loose Water in a confining space.)

G_2Z_2 = righting arms of ship after considering the weight changes, Loose Water Effects and the off center shift of G of ship due to horizontal positions of weight.

At any one instant, the righting arms, G_2Z_2, can be seen from the diagram of forces acting to be:

$$G_2Z_2 = AZ_a - AG_V \sin\theta - G_VG_2 \cos\theta$$

AZ_a = Original righting arms derived from Cross Curves of Stability for particular displacement.

$AG_V \sin\theta$ = loss of righting arms due to vertical shift of G up of shift and Loose Water Effects plotted as a sine curve.

$G_VG_2 \cos\theta$ = loss of righting arms due to off center shift of G of ship plotted as a cosine curve.

Therefore the expression G_2Z_2 can be written

$$G_2Z_2 = AZ_a - (AG_V \sin\theta + G_VG_2 \cos\theta)$$

Hence the expression $(AG_V \sin\theta + G_VG_2 \cos\theta)$ is the total loss in righting arms from the original righting arms developed from the Cross Curves.

Let us assume $AG_V = a$, and $G_VG_2 = b$,
Now, loss of righting arms of GZ or $\triangle$ GZ

$$\triangle GZ = AG_v \sin\theta + G_vG_2 \cos\theta$$
$$= a \sin\theta + b \cos\theta$$

Note: c can equal any value, so $\frac{c}{c} = 1$

$$= \frac{c}{c}(a \sin\theta + b \cos\theta) = c\left(\frac{a}{c}\sin\theta + \frac{b}{c}\cos\theta\right)$$

If a and b are taken as the sides of a right triangle, then we can assume c as the hypotenuse, in fact c is hypotenuse of right triangle formed by the shift of G from A to G_V to G_2, as illustrated in Fig. 5.

i.e., $c = AG_2$

Let $\angle\ G_2AG_V = \psi$; so

then $\sin\psi = \frac{b}{c}$

$\cos\psi = \frac{a}{c}$

$c = \sqrt{a^2 + b^2}$

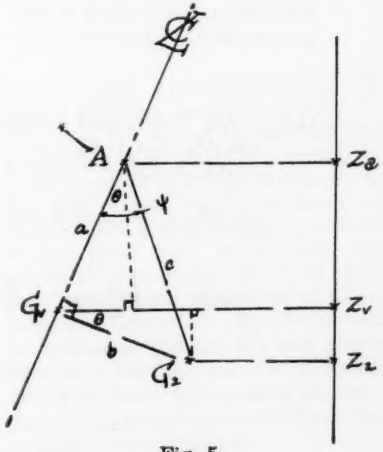

Fig. 5

$$\text{Therefore, from } \triangle GZ = C\left(\frac{a}{c}\sin\theta + \frac{b}{c}\cos\theta\right)$$

$$= C(\sin\theta\cos\psi + \cos\theta\sin\psi)$$
$$= C\sin(\theta + \psi)$$

where C is hypotenuse of right triangle whose sides are a and b, or $C = AG_2$

and $\psi = \tan^{-1}\frac{b}{a}$ or is $\angle\ G_vAG_2$, angle which shift of G makes with $\mathbb{E}$ of ship.

From the above it can be seen that to arrive at the Correct Statical Stability Curve, we need to deduct from the original righting arms, AZ_a, the values of c sin $(\theta + \psi)$ for all angles of roll, i.e.,

$$G_2Z = AZ_a - c\sin(\theta + \psi)$$

Where amplitude of sine curve is $C = AG_2$ and phase angle is ψ or $\angle\ G_2AG_v$ or advancement of sine curve is ψ degrees to the left.

After plotting a Statical Stability Curve for a particular displacement from the Cross Curves of Stability, a plot of a sine curve of c sin $(\theta + \psi)$ can be drawn. Then the graphical difference of the two curves is the Residual (Remaining) Stability. The sine curve of c sin $(\theta + \psi)$ is actually a sine curve whose amplitude is C, i.e., maximum value is c, and whose phase angle is ψ, i.e., the 0 value of the curve begins at $-\psi$ before the 0°, we may say that the sine curve has shifted to begin at ψ to the left.

Note: If the shift of G of ship is *downward* and off center, the following occurs; refer to Fig. 6:

This may be as a result of solid flooding low in ship and off center compartments.

$$G_2Z_2 = AZ_a + AG_v\sin\theta - G_vG_2\cos\theta$$
$$\text{Let } AG_v = a,\ G_vG_2 = b$$
$$= AZ_a + a\sin\theta - b\cos\theta$$
$$= AZ_a + \frac{c}{c}(a\sin\theta - b\cos\theta)$$
$$= AZ_a + c\left(\frac{a}{c}\sin\theta - \frac{b}{c}\cos\theta\right)$$

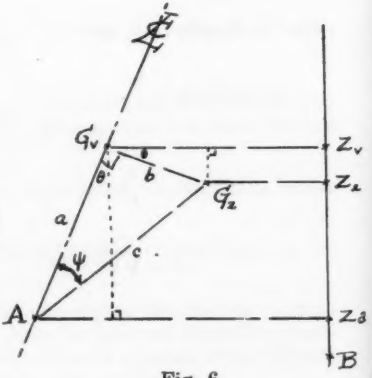

Fig. 6

Let $c = AG_2$, ψ = phase angle $\angle G_1AG_2$, $\sin \psi = \frac{b}{c}$

$$\cos \psi = \frac{a}{c}$$

$$= AZ_a + c (\sin \theta \cos \psi - \cos \theta \sin \psi)$$
$$= AZ_2 + c \sin (\theta - \psi)$$
$$\therefore \triangle GZ \text{ (loss or gain)} = + c \sin (\theta - \psi)$$

Here, since $c \sin (\theta - \psi)$ is positive, we add graphically the sine curve of $c \sin (\theta - \psi)$ to the Uncorrected Statical Stability Curve to get the Residual Statical Stability.

CONCLUSIONS

With the use of the one sine curve plot, it can be seen that elimination of plotting two curves and reduction of time consumed in plotting are the results. However, the plotting of a sine curve of $c \sin (\theta + \psi)$ is a rather involved operation, easily accomplished by the adept Student of Mathematics. With this in mind, it necessitates the development of a method whereby the user of this exercise can readily evaluate his Stability picture, for the time of Damage Control Assistants aboard ship is not unlimited. Hence a graphical method in the form of a Maneuvering Board, with adaptations of a Slide Rule and Nomographs is developed as the ultimate demand.

A Damage Control Assistant without a keen facility in Mathematics, Trigonometry, and Curve Plotting can arrive at a relatively approximate picture of Stability by the plotting of one curve in relation to another, and physically plotting the difference. Hence a *"Stability Plotting Board"* as it can be known, should be developed to accomplish the operations developed here in theory and in previous applications.

CONSTRUCTION OF STABILITY PLOTTING BOARD (S.P.B.)

A plotting arrangement develops with several factors to be considered. One of these factors, the scale to be employed, receives consideration in how large an arrangement can be handled. It can be seen that the greater the scale, the more accurately we can plot values, and graphically interpret their values.

Primarily, this Stability Plotting Board can consist of three flat surfaces (2 poster boards and 1 sheet of plastic).

The first and most important sheet (on Poster Board No. 1) would be the plot of sine curves for amplitude values of 0 to maximum values of GZ + 2, GZ values noted from the Cross Curves of Stability, plotted in graduations of 0.2 feet. Adjacent to this plot of sine values, at about an angle of 40°, a grid should be plotted to the same scale to simulate the graphical movement of G of ship, showing angular movement of G in respect to Centerline (℄). To the left of Reference line for 0°, and above Reference line for $GZ^* = 0$, a cutout should be made to represent one section of displacement vs. GZ from the Cross Curves of Stability.

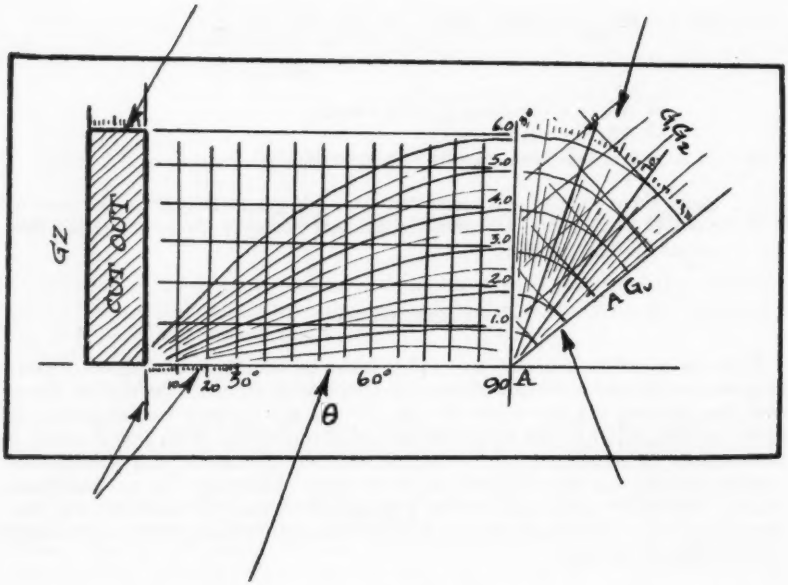

Fig. 7

Let us call this Poster Board No. 1, the "Grid Board." Refer to Fig. 7.

Secondly, on the Poster Board No. 2, another plot of the Cross Curves of Stability against the various displacements, using the same scale for righting arms (GZ) as the "Grid Board." and scale of displacement to fit into the same range used for angular measurement, i.e., displacement unit of 9,000 to 10,000 tons (or 20,000 to 30,000 tons), so as to fit into the open "Cut Out" Section in the "Grid Board." Let this Posterboard No. 2 be known as "Cross Curves Board."

Lastly, on the plastic sheet, upon which soft crockery marking crayon can be used, two lines are to be scribed to correspond to the baselines of the "Grid Board" (i.e., a horizontal line for $GZ = 0$, and a vertical line for $\theta = 0°$). Let this Plastic Sheet be known as the "Rider."

Note that all of these sheets are to be able to slide against a fixed track, secured to the "Grid Board" or an external edge, and all reference lines are to correspond.

Recommendations for a Scale:

The general dimensions of the S.P.B. could be about 40″ x 30″; whereby on the "Grid Board"—on GZ axis, 2″ = 1 ft.; on θ axis, 2″ = 10°.

"Cross Curves Board"—on GZ axis, 2″ = 1 ft.; on displacement axis 2″ = 1000 tons or any convenient unit.

The three boards are illustrated in Fig. 8 and Fig. 9.

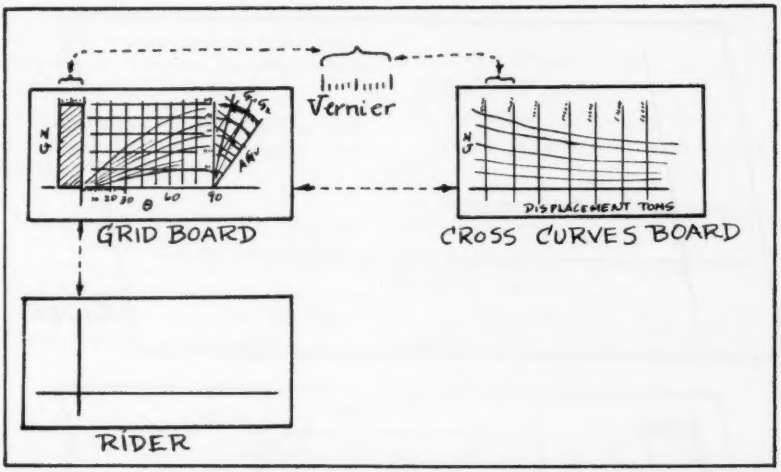

Fig. 8

OPERATION OF STABILITY PLOTTING BOARD (S.P.B.)

With the "Cross Curves Board" under the "Grid Board," and the "Rider" on top of the "Grid Board," all riding on their bottom edges in relation to a fixed track, the S.P.B. is ready for operation as follows:

1. Align the "Rider" with the "Grid Board," so that the Reference Lines are lined up.

2. Move the "Cross Curves Board" until the desired displacement appears on the right hand side (Vertical Reference Line) of the cut out of the "Grid Board."

3. Plot in the Statical Stability Curve with the Crockery Crayon on the "Rider" at correct intervals corresponding to that on the "Cross Curves Board." (Note: this Statical Stability Curve is uncorrected)

4. Plot the movement of G of ship from A to G_v to G_2 on the "Rider" with the soft crayon, following the angular grid, i.e., plot the distance AG_v on the AG_v axis, and then along G_1G_2 axis plot the off center shift of G of ship.

5. The distance AG_2, amplitude of c sin $(\theta + \psi)$, actual movement of G_v from A is noted. Follow the circular curved path and note the distance above A this is. This AG_2 determines the sine curve to be traced. Also, note the angular movement of the AG_2 line with the $\measuredangle$ (AG_v axis). This angle is the phase angle ψ. This determines the relative shift of the "Rider" (actually of the sine curve).

6. Shift the "Rider" to the *right** so that the Reference Lines on the "Rider" has moved the angle ψ in relation to Reference Line on the "Grid Board."

*Note: Shift "Rider" to the left when shift of G is down and off center.

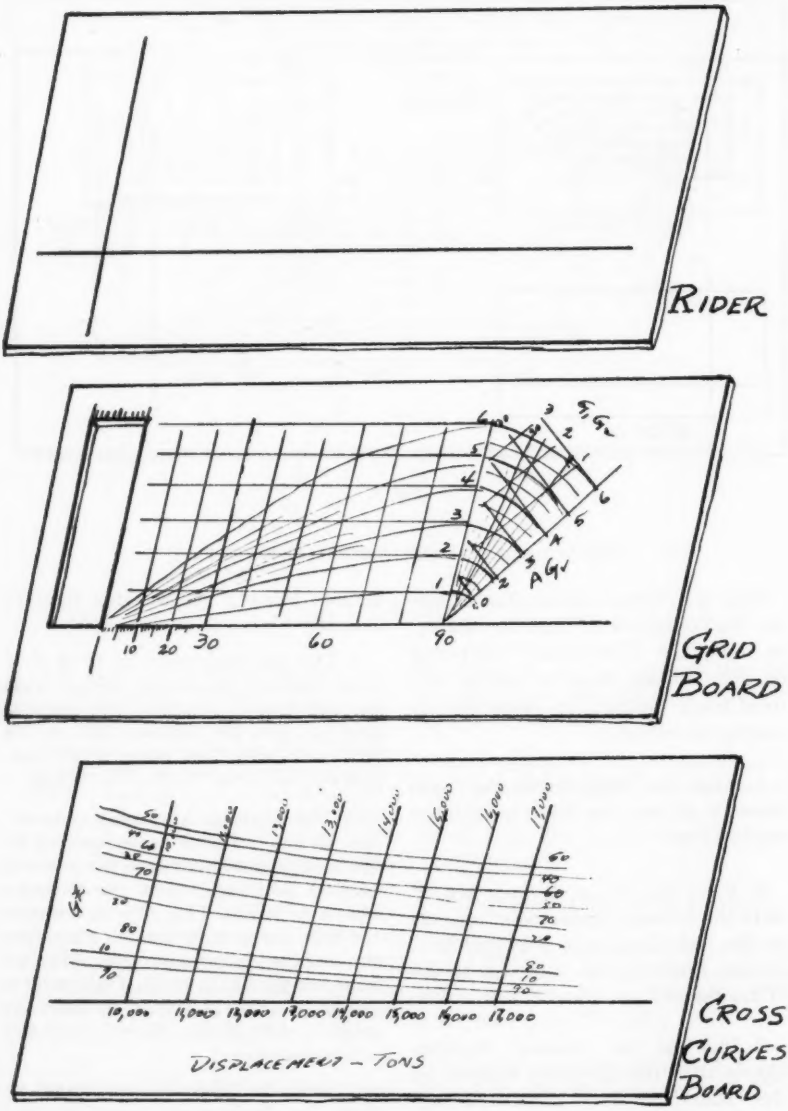

Fig. 9

7. Now, on the "Rider," trace in the sine curve determined by value AG_2, following as a guide the sine curves already on the "Grid Board."

8. Now, move "Rider" back so that its Reference Lines correspond with those on "Grid Board."

The graphical difference between the two curves is the Remaining Statical Stability. This, plotted on the Horizontal Reference line, is the Residual Statical Stability Curve for this situation for analysis as demanded.

The following can be determined:

1. Angle of List, if any.
2. Range of Stability.
3. Maximum Righting Arm.
4. Angle of occurance of maximum GZ.
5. Dynamic Stability remaining or lost, as desired.
6. Approximate amount of Initial Stability, GM, if desired.
7. Righting Moment Curve, if desired.

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LIQUID DIELECTRICS

ACKNOWLEDGMENT

Dr. A. H. Sharbaugh and Dr. R. W. Crowe, Research Associates in the Physical Chemistry Section of the Knolls Laboratory, are the authors of this article which was published in the May 1954 issue of *General Electric Review*.

Although solid insulators play an all-important role in the electrical industry—that of isolating conductors from one another and from ground while supporting them physically—liquid insulators are equally important in many electrical products. Transformers, circuit breakers, capacitors, and cables are some of the more common devices that utilize liquid dielectrics. In the transformer industry alone, insulating oil by the tens of millions of gallons is used annually.

Through a better understanding of how liquid dielectrics behave in electric fields, engineers have the opportunity to further increase the operating efficiency of their products. For the development of liquids with better electrical properties will yield transformers of greater power capacity per unit volume, capacitors of greater electric capacity per unit volume, and so on.

What electrical properties determine the performance of a liquid dielectric? Primarily they are: 1) ability to resist breakdown under electrical stress, 2) the electric capacitance per unit of volume determined by the dielectric constant, and 3) loss factor—the energy loss per unit volume per cycle. These properties depend on the liquid's operating temperature and frequency as well as on the structure of its constituent molecules.

Let's look first at electrical phenomena in liquids at low voltages, then proceed to the less understood phenomenon of electrical breakdown at much higher voltages. (We'll confine our attention to electrical properties alone—not the physical ones such as heat transfer and mechanical forces.)

DIELECTRIC CONSTANT

In deciding what liquids may be classed as insulators, you can arbitrarily select those having resistivities greater than a certain value, say, 10-million ohm-centimeters. (An ohm-centimeter is the resistance between opposite faces of one cubic centimeter of the liquid.) On this basis, for example, you would class water as a liquid insulator, although its resistivity is a million times smaller than other commonly used insulating liquids.

Actually, the application dictates the

permissible lower limit of resistivity. Thus water, with a high dielectric constant, can be a perfectly respectable dielectric in some applications and an extremely poor one in others.

What do we mean by a dielectric constant? Perhaps the most familiar property of liquid dielectrics is the capacitance increase observed when an air capacitor is immersed in a liq-

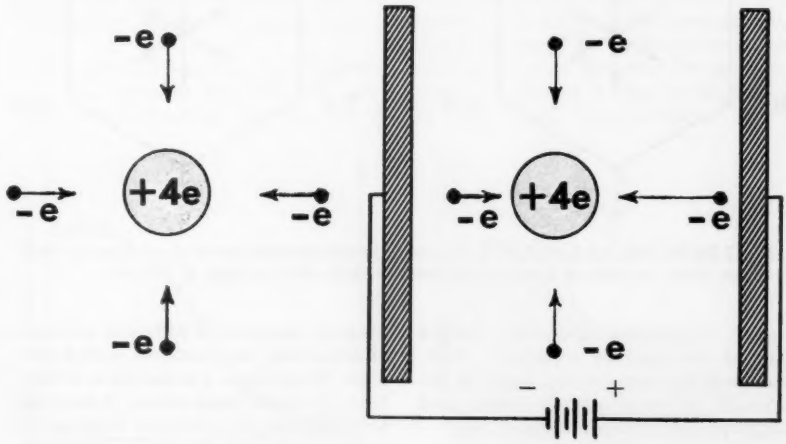


Fig. 1. INDUCED DIPOLES are formed in a neutral atom (*left*) when placed in an electric field (*right*). Arrows indicate the magnitude and direction of polarization.

uid. In fact, this ratio of the liquid- to air-filled capacitance is often used to define the dielectric constant of the liquid in question. Explained in this way, its magnitude becomes a property of the liquid, independent of the measuring voltage or geometry of the test capacitor. Extremes of such ratios for liquid dielectrics range from 1.05 for liquid helium to 78 for water; most commonly used liquids have dielectric constants between 2 and 5. On the other hand, the dielectric constants of all gases are very nearly unity. And so, gases do not offer the larger capacitances per unit volume that liquids do.

POLARIZATION

The dielectric constant varies with the temperature and molecular structrue of a liquid and with the frequency of the applied voltage wave. To understand the reason for this variation and why liquids differ broadly in their dielectric properties, you need to become acquainted with a phenomenon called *poralization*, common to all liquid dielectrics.

When a unit positive charge $+q$ and a unit negative charge $-q$ coincide in space, their electric fields cancel one another and their net charge is zero. If they are displaced a distance

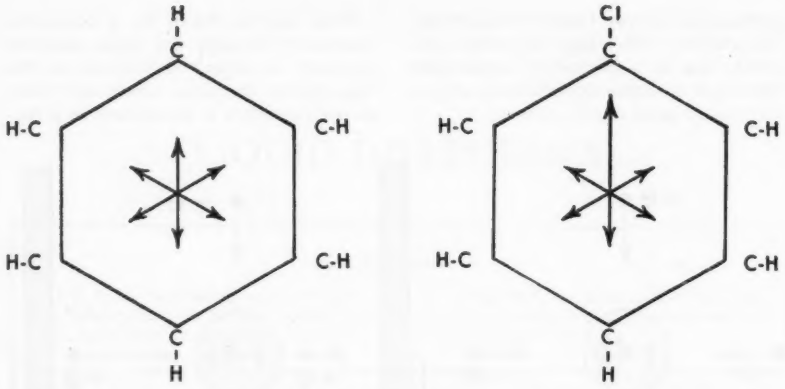


Fig. 2. ELECTRICAL BALANCE of a neutral benzene molecule with six dipoles (*left*) is upset when an atom of hydrogen is interchanged with an atom of chlorine.

l apart, a resultant field arises. Such a pair of charges now constitutes a dipole, and has a moment μ equal to the product of their displacement and magnitude of either charge, or lq.

For example, an atom (Fig. 1, left) with four electrons symmetrically located about a nucleus of four protons is the equivalent of four dipoles. The moment of each pair, electron and proton, is represented by the length and direction of the arrows. You can see in this instance that all the individual dipoles balance each other and that the atom as a whole is electrically neutral. But place the same atom in an electric field between the plates of a capacitor and see what happens: Now the individual dipoles no longer mutually cancel each other (Fig. 1, right) because the electrons are attracted to the positive plate. Conversely, the positive nucleus is slightly displaced toward the negative plate. The resultant dipoles are called induced dipoles because they exist only by virtue of the externally applied field.

You may remember from your studies of chemistry that different kinds of atoms have different amounts of attraction for electrons, called *valence*. Thus, when a molecule is formed from its constituent atoms, it may not be completely in electrical balance. As an example, take first the molecular structure of benzene (Fig. 2, left), a common dielectric liquid. Here the individual dipoles arising from the different electron affinities of carbon and hydrogen are in complete electrical balance. If, however, a chlorine atom is substituted for one of the hydrogens (Fig. 2, right) there is no longer complete neutralization of the individual dipoles, and the molecule is out of electrical balance. This kind of molecule has a *permanent* dipole moment because it doesn't owe its existence to any external electric field.

The general term polarization refers to the movement of electric charges within a molecule in response to an applied field. You may further classify it according to the kind of body that carries the charge—electronic, atomic, or dipole. Electronic polarization, explained in connection with the atom, involves the relative displacement of electrons with respect to their atomic

nucleus. Atomic polarization, on the other hand, is caused by shifts in the equilibrium positions of atoms within the molecule with respect to each other. Dipole polarization (not illustrated) arises when the randomly oriented permanent dipoles of a molecule are oriented by an applied electric field.

At a given frequency and temperature, the value of the dielectric constant will depend on the number of different kinds of polarization that can form. Although all liquids will have electronic and atomic polarizations that contribute to their dielectric constants, the amount of dipole polarization will vary greatly according to the magnitude of the dipole moment. If the molecule is electrically symmetrical, it will be zero. The dielectric constant of a liquid may therefore be large or small, according to the arrangement of atoms within its molecules.

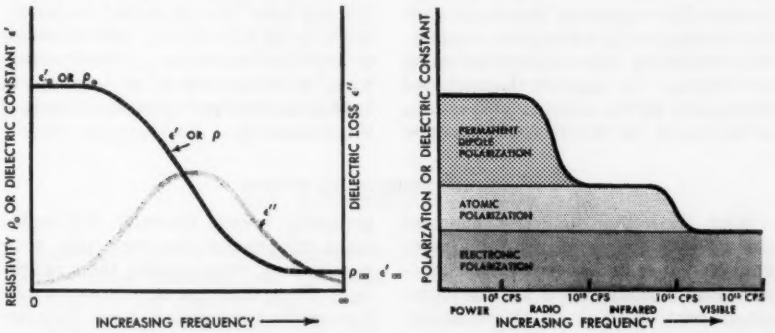


Fig. 3. FREQUENCY DEPENDENCE of the dielectric constant, resistivity, and dielectric loss (*left*) is depicted for one type of polarization. Superimposing curves, shown in heavy black, for the different polarizations result in the composite picture.

FREQUENCY DEPENDENCE - - -

If you use a low frequency or d-c voltage to measure the dielectric constant of a liquid having permanent dipoles, all the polarizations will be complete, and you'll obtain the highest possible value of dielectric constant. If, however, you increase the frequency of the applied a-c voltage, the direction of the electric field may be reversed before polarization has time to form. This leads to a decrease of dielectric constant from some steady-state value ϵ'_0 (Fig. 3, left) at low frequencies to another steady-state value ϵ'_∞ at some higher frequency.

The size and weight of the various charge carriers give a clue to the time required for the different types of polarization to form. Electronic polarization (Fig. 3, right), involving the extremely light and small electron, persists from power frequencies through the visible frequencies. Atomic polarization, requiring the movement of the heavier atom, usually does not persist beyond the infrared range. Dipole polarization needs even longer times because it requires the movement of entire molecules, and usually it contributes to the dielectric constant only at power and radio frequencies.

One by one the permanent dipole

and atomic polarization cease to contribute to the total dielectric constant as the frequency is increased from d-c or low-power frequencies to the higher visible frequencies. For this reason water has a dielectric constant of 78 at power frequencies (60 cps) and only 2 at visible frequencies (10^{14} through 10^{15} cps).

The heat generated in a liquid dielectric under stress is determined by the combined effect of: 1) a frequency-independent resistivity measured with d-c voltage and 2) a frequency-dependent resistivity that contributes when a-c voltage is applied. Determined principally by the number of free ions in the liquid, the d-c resistivity can be reduced to an extremely small value in the case of organic fluids. For example, carefully purified water has a d-c resistivity of about 10^7 ohm-centimeters. Thus it represents a highly "lossy" liquid dielectric. On the other hand, a hydrocarbon oil—a liquid such as petroleum containing only carbon and hydrogen—may have a d-c resistivity of 10^{15} ohm-centimeters, making it almost a perfect insulator.

Referring back to Fig. 3 (left), you can see how the measured resistivity starts at its d-c value ρ_0 and decreases to some limiting value ρ_∞. The loss factor ϵ'' is a measure of the amount of heat generated per cycle as a result of this resistivity.

- - - AND TEMERATURE EFFECTS

Why does the dielectric constant change with temperature? Remember that its value at any particular temperature is determined by the combined contributions of the different kinds of polarization. In the instance of electronic and atomic polarization, the influence of temperature is slight because these polarizations are affected only as the density of the liquid changes. Hence, they become slightly smaller as the liquid's temperature is raised, because the number of contributing atoms per unit volume becomes smaller. Conversely, they become slightly larger as the temperature is lowered.

A much stronger temperature dependence is experienced in dipole polarization: the entire molecule rotates instead of just its charges being displaced. Because a rise in temperature generally lowers viscosity, the molecules experience less molecular friction as they rotate among their neighbors. They undergo an increased motion as the temperature rises. This action promotes a random orientation of the dipoles that opposes the ordering influence of the applied electric field. And so, the net effect of temperature increase on dipole polarization is a lowering of the measured dielectric constant.

(Because the dielectric "constant" of a liquid may depend strongly on frequency and temperature, you might conclude that the name isn't too descriptive. This is true. However it has gained rather universal acceptance, although various other terms are occasionally found in literature. One that is sometimes used is specific inductive capacity, and another is dielectric coefficient.

HIGH-VOLTAGE PHENOMENA

When liquid dielectrics are utilized as insulating material in high-voltage equipment, they are important because of a property differing entirely from that associated with the polarization of molecules. This difference arises from their ability to withstand high electrical stresses for long periods of

time. For these purposes, engineers usually prefer liquids that are thermally stable and nonflammable.

If the voltage applied to any dielectric insulator placed between two metal electrodes is increased sufficiently, an electric spark will pass through it. When this occurs the insulator has broken down electrically. And the heat accompanying such a breakdown spark usually results in the accumulation of a large quantity of decomposition products along its path. Because such products weaken the dielectric even more, an initial breakdown often renders a piece of equipment permanently inoperative.

When designing high-voltage equipment using liquid insulation, the engineer wants to know what he can expect of a liquid exposed to high electric fields. Unfortunately, this isn't always predictable. Any property that deals with the violent destruction of matter is often complicated and difficult to reproduce. As a result, the phenomenon of electrical breakdown in liquids is not well understood as yet. Surprisingly enough, the great influence of extraneous factors not associated with the liquid itself makes it difficult to correlate breakdown with any known molecular properties. The engineer, then, is forced to use abnormally large safety factors when designing his equipment.

WHAT IS ELECTRICAL BREAKDOWN?

The appearance of an electric spark is certainly evidence of electrical breakdown; but it doesn't tell you why breakdown occurred. Extremely large currents in sparks do, however, suggest this: Electrical breakdown involves the failure of the insulator to retain its initially high electrical resistance. Hence, a general definition of a liquid's breakdown voltage is that amount of voltage required to convert it rapidly from an insulator to a conductor.

How does such a conversion take place? And what does the magnitude of the voltage have to do with electrical breakdown? Perhaps the most widely accepted theory of explaining this phenomenon deals with the electron avalanche.

Consider a system (Fig. 4) composed of a liquid dielectric placed between two parallel-plate metal electrodes. Choose the system so that the electric field will be homogeneous throughout. When you apply a voltage to the electrodes, free electrons emitted by the cathode—or already present in the liquid itself—are accelerated toward the anode. This acceleration will continue until the rate at which electrons lose energy by collision with molecules just equals the rate at which they gain energy from the electric field. Under these conditions the electric current will remain small. If, however, you in-

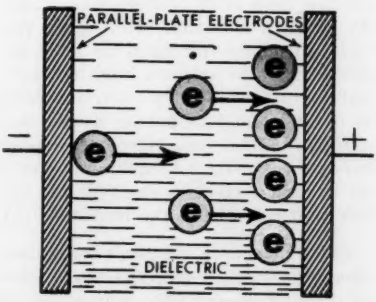


Fig. 4. ELECTRON AVALANCHE begins when a free electron gains enough energy to knock another electron from a molecule.

crease the voltage so that each free electron gains sufficient energy to knock another electron from a molecule of the liquid—called *ionization*—the number of current carriers, and the current, is multiplied by two.

To take it a step further, suppose you increase the voltage until each starting electron can multiply in this manner a number of times as it crosses the gap. Since each new electron produced by collision is also free to undergo the same process, the result is an electron avalanche. Mathematically it works like this: If a single starting electron makes n ionizing collisions while crossing the gap, then 2^n electrons will reach the anode. When n reaches some critical value, the electric current through the liquid will be high enough to lead to a runaway process culminating in the spark. Thus, you can define electric strength as the voltage that will just cause breakdown divided by the distance between electrodes.

THEORY AND PRACTICE

From what has been said you might expect the electric strength of a liquid to be controlled by its ability to resist the acceleration of electrons to those energies causing ionization. This would be true only under ideal conditions. However, as mentioned earlier, many extraneous factors often overshadow the properties of the liquid itself. Usually they prevent measurement of the liquid's maximum electric strength.

Of these complications, one of the most serious is the shape of electrodes. Seldom do you find smooth, flat electrodes in actual equipment. Irregularities on electrode surfaces—such as sharp edges or points—intensify the electric field in their immediate vicinity. Such a situation often gives rise to localized electric fields far more intense than the uniform field throughout the liquid. And if their intensity is great enough, electron avalanches can be sufficiently large to cause breakdown. You would thus measure an apparent electric strength far below that realized in the uniform field.

Often, however, electrode irregularities give rise to electron avalanches of limited magnitude—too small to cause complete breakdown directly. This is so because the field strength throughout most of the liquid is low, and localized avalanches are unable to proceed through the entire gap before they are snuffed out. (The occurrence of ionization leads nonetheless to a gradual decomposition of the liquid and in time may cause its failure. Engineers commonly call pre-breakdown avalanches of this kind *corona*—observed electrically as small bursts of current.)

Closely associated with the effect of electrode shape are small particles on the electrode surfaces or suspended in the liquid. Having a dielectric constant higher than the surrounding medium, these particles will tend to move into the regions of highest electric field. Their effect is to create intense localized fields and cause premature breakdown.

But perhaps the most difficult external factor to control in the laboratory is the electrode material itself. Here's why: The electric fields involved in the breakdown of liquids are of the order of one-million volts per centimeter. At these voltages, most metals emit electrons profusely by a process known as *field emission*, or *cold emission*. The electric field at which this emission becomes extensive has a high sensitivity not only to the kind of electrode metal but also to the nature of its surface. For example, if a highly

polished electrode is partially covered with an oxide film, its emission characteristics may vary a considerable amount from one part of its surface to another.

Again, if electrons are emitted by this mechanism at a faster rate than they can be swept to the anode by the electric field, there results a large electronic space charge near the cathode. This gives rise to an intense field in the vicinity of the anode. And such behavior invariably results in low values of the apparent electric strength of the liquid.

THERMAL BREAKDOWN

Although the distortion caused by intense localized fields may lower the apparent electric strength of a liquid, it doesn't alter the general mechanism by which disruption of the dielectric occurs. For example, another complication that may not be considered external doesn't depend on field distortion at all. If ionic impurities are present in the liquid, the application of an electric stress may cause a large enough current to flow even without ionization to cause a definite increase in temperature. The same thing can happen if the liquid itself possesses a relatively low electrical resistance at low fields.

This rise in temperature is usually observed in liquids that require long-time exposure to high voltage. If it becomes high enough, the liquid may decompose thermally. More often, however, bubbles of once-dissolved gases —or vaporized liquid—that are ejected at the elevated temperatures cause premature failure. This phenomenon is called *thermal breakdown.*

LABORATORY TRICKS

You might infer from what has been said that any measurement of the electric strength of a liquid has little or no meaning in terms of the liquid's structure and composition. This isn't necessarily true. For if you make a concentrated effort to either fix or remove extraneous factors, it's possible to observe significant differences in the electric strengths of liquid dielectrics. You can do this by carefully purifying and filtering the liquids before testing and by carefully selecting and preparing electrodes.

Hemispherical electrodes are usually used to test liquid dielectrics in the laboratory for a number of reasons. For one, they are relatively easy to fabricate and polish. For another, if their radii or curvature are large compared to the gap spacing between them, a small region in the center of the gap will have a configuration approaching that of two parallel-plane electrodes. This electrode curvature, reducing the electric field in all other parts of the gap, limits breakdown to the small center region of the electrodes where the field is nearly uniform. And by using rectangular voltage pulses of approximately one microsecond's duration, the danger of interference from thermal breakdown is easily removed. (When pulses of such short duration are applied singly to the breakdown cell, there's not enough time for harmful temperature changes to take place.)

With these techniques it's possible to measure the electric strengths of liquid hydrocarbons within an accuracy of

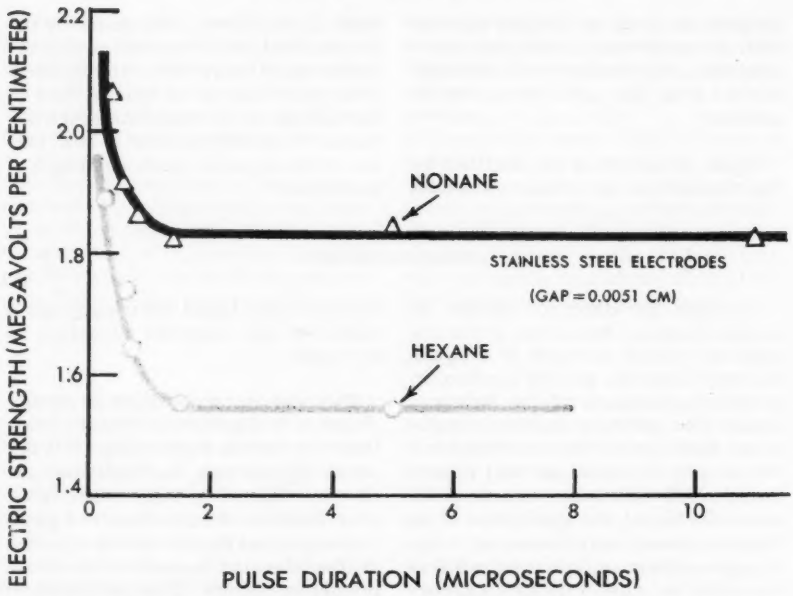


Fig. 5. INVERSE RELATIONSHIP of pulse duration to liquid-hydrocarbon strength ends beyond one microsecond. Beyond 10 microseconds, thermal effects complicate matters.

four per cent or less. From such measurements (Fig. 5) the electric strength is found to be independent of pulse duration for times greater than one microsecond. Thus the time-independent value of electric strength is the same value you would measure under long-time voltage application—if you could prevent thermal effects. (The latter begin to interfere when pulse duration reaches a value greater than 10 micro-seconds.)

Field emission effects, on the other hand, can only be fixed but not eliminated. And so, the time-independent value of electric strength represents a combined property of the liquid and the electrode material.

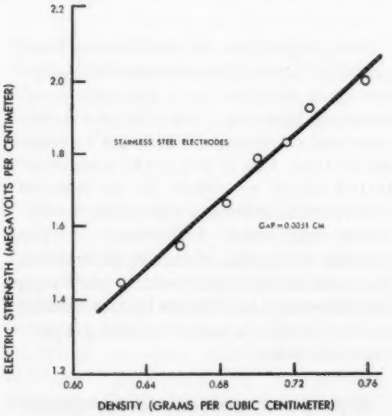


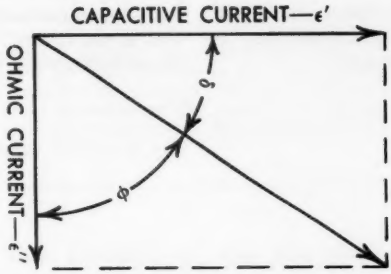
Fig. 6. ELECTRIC STRENGTH of a liquid hydrocarbon, stressed by high-voltage pulses of short duration, is a function of the liquid's density and molecular structure.

HOW THE LOW-VOLTAGE GOODNESS OF A LIQUID DIELECTRIC IS DETERMINED

That most liquid dielectrics are not perfect insulators has been experimentally proved. But they do have a measurable power loss that's manifest as heat. This fact is taken into account by the equation

$$\epsilon^* = \epsilon' - j\epsilon''$$

where ϵ^* is a liquid's complex dielectric constant, having direction as well as magnitude. Its real component ϵ' is the absolute value of the dielectric constant and gives rise to the current out of phase with the applied voltage. The imaginary component ϵ'', called the loss factor, is a measure of the in-phase current or the heat generated per cycle of applied voltage; j equals $\sqrt{-1}$. This is shown graphically—



A quantity expressing the merit of a liquid dielectric is the loss tangent, defined by the relationship, tan $\delta = \epsilon''/\epsilon'$. As you can see from the diagram, the complement of the angle δ is ϕ; and the cos ϕ is defined as the dielectric's power factor. For low-loss liquids, δ is almost zero, making ϕ nearly 90 degrees; therefore, tan δ = cos ϕ. And so, the loss tangent equals the power factor when tan δ is less than 0.1.

Liquids having a power factor less than about 0.05 at their operating frequency are usually considered satisfactory for commercial use. To give you an idea of magnitudes, the Table lists values for some commonly used liquid dielectrics, including water.

DIELECTRIC PROPERTIES OF SOME LIQUIDS
AT 25 C AND 60 CPS

Liquid	ϵ'	ϵ''	Loss Tangent (Tan δ)	Power Factor (Cos ϕ)
Pyranol†	5.3	0.005	0.001	0.001
Hydrocarbon oil	2.2	0.002	0.001	0.001
Dibutyl sebacate	4.5	0.040	0.010	0.010
Water	78.0	78,000	1000	1.000

†Reg. Trade-mark of General Electric Company

By applying the pulse technique to liquid hydrocarbons of different molecular weight (Fig. 6), it is found that electric strength increases in a linear fashion with the density of the liquid.

THE SUMMING UP

In a general way, some of the more important electrical properties of liquid dielectries have been presented. And though these properties were divided into two distinct groups—low and high voltage—it doesn't necessarily mean that there is any line sharply dividing dielectrics in usage. For in many applications you'll find liquids with good characteristics at both high and low voltages.

The relationship of a liquid's electric strength to its molecular properties is obviously of value to the engineer in search of a liquid dielectric to fill his specific need. But unfortunately, theories that explain such correlations —or predict the electrical behavior of liquids in high dielectric fields—are presently qualitative at best. Perhaps more information of the type discussed will, in the future, contribute to a better understanding of liquid dielectrics.

RECOGNITION FOR ENGINEERS

JOHN W. SAWYER

THE AUTHOR

Graduated from North Carolina State College with a BSEE in 1933. Served in U. S. Merchant Marine. Graduated from Ohio State University with a BME in 1938. Active service in U. S. Navy as a Lieutenant Commander until 1949. Has been employed by the Bureau of Ships in the Turbine and Gear Branch since 1949. Is now staff assistant for research, development and new construction in this Branch. Currently president of The Association of Senior Engineers of the Bureau of Ships and chairman of the Washington Section of The American Society of Mechanical Engineers.

Most individuals react favorably to recognition for the accomplishment of difficult tasks. Such reactions can take the form of renewed effort to do an even better job. There may also be a sympathetic reaction resulting from the recognition of outstanding work. This can result in improved performance on the part of colleagues. Engineers are individuals with strange likes, dislikes and interests. They are as human in certain respects as John Doe and will react just as favorably to praise and recognition.

In general, engineers are not publicity seekers. Neither are they noted for their generosity in bestowing publicity. Some in the engineering profession feel, perhaps justly so, that only in rare and unusual circumstances does a fellow engineer warrant praise or recognition by his own profession. However, one of the large engineering societies in the United States with more than 35,000 members, realizes the importance of recognition for engineers and states in its pamphlet on *Honors and Awards* "An important purpose of honoring men is to encourage and inspire them to reach even greater heights of professional achievement."

During recent years engineering and engineers have been brought more and more to the attention of the public. With the growing demand for engineering talent there is a need for greater recognition of individuals who have accomplished outstanding engineering works. This need is two-fold. The engineer should be recognized for superior performance to show appreciation, and to encourage him to greater efforts. Then, an engineer, thus honored, can serve as an inducement to others to enter this field as well as an example for his colleagues to follow.

Most professional societies, have established criteria for honoring their members for outstanding achievements. Some industrial organizations also make awards to personnel for exceptional contributions. The systems vary widely between the many professional groups as well as within industries. They have, as a rule, been developed through years of experience.

In order to present some idea as to the number of awards made by a group of professional people the frequency rate, the number of awards per man-year of engineering time, will present a good general picture. One professional society with a membership of some 30,000 has machinery established to make ten awards each year. However, it is not mandatory to bestow these unless there are instances that merit award. Assume for example, that only ten awards are made in a given year. This gives an award frequency rate of one award for each 3,000 man-years of engineering.

An organization employing some 1,000 engineers and scientists engaged in a wide variety of work makes no awards to single out individuals for major scientific accomplishments. Here, engineers are actually making real contributions to the many complex problems confronting the organization and no steps are taken to select the outstanding people and give them recognition. The award frequency of this organization is obviously zero.

An examination from a different point, of awards made by one of the above professional groups is of interest. Assume that the average engineering life time is forty man-years. On the basis of 40 years per engineering life time the award frequency ratio cited for the group with 30,000 members is 1 to 75. This means that once in 75 engineering life times an award is made to an engineer for outstanding achievement.

The engineering professions benefit when the appropriate honors and awards are bestowed on an engineer. The prestige of the profession is enhanced and young people with technical interests are encouraged to enter engineering work.

It has been estimated that the United States needs about 40,000 engineering graduates each year to meet industrial and military needs. The supply at present is 12,000 to 17,000. This shortage is not a very comforting one. It can be alleviated to some degree by greater recognition of engineers. Such public notice will be a real step towards presenting the engineering profession in a more favorable light to the public and to those people who will be our engineers of the future.

Awards should not be made to the extent that they no longer convey any token of merit or prestige. Neither should they be so few as to become legendary or mythical. Opinions have been advanced that the selection of worthy recipients is difficult and time-consuming. It is well known that the dividends received vary in direct proportion to the amount invested. In other words, it can be said that the more difficult the job the greater the return. If selection of recipients is a difficult task the overall gain to the profession is greater than if the task were an easy one. Engineering has advanced to its present level by the solution of difficult problems.

What can be done to favorably increase the awards frequency rate? This rests with industry, professional societies, government, educational institutions, and any other group that utilizes the services of the engineer. These various groups can take stock

of awards they now make, analyze them critically and ask are they actually sufficient to cover the many phases of engineering under their direction or control. They can also review areas where awards and honors are not made and take steps to establish new ones as needed.

Practically every industry can greatly increase its engineering awards. Professional societies can do much by establishing new national awards and encouraging local chapters and sections to set up their own award systems. Government, where every type of engineering is found, can make great advances in this increased recognition. Some congressional action is now being planned on this matter.

Adequate awards and honors to recognize outstanding engineering accomplishments can ultimately save industry, government and the taxpayer money. Engineering can be made more appealing to young men and women if the public is made aware of the contributions made by members of the profession. The gains to be realized from an investment by professional societies are tangible.

It is up to the engineer and the profession to see that these gains are achieved. Surely the engineers of America are worthy of *honorable mention* more often than once in 3,000 man-years of engineering or once in 75 engineering life-times.

WIND TUNNELS

ACKNOWLEDGMENT

This article discusses the vast specialization of wind tunnels and the great spread in their numbers, locations, sizes, air speeds, operating conditions and functions,—brought about by the rapid rise in airplane speeds and new types of power plants, rockets and guided missiles. It was prepared by Mr. C. A. Scarlett and was published in the March 1954 issue of *Westinghouse Engineer*.

An airplane—even an old DC3—is deceptively sleek in appearance. The wings must, to be sure, be of the right section and placed at the right angle—aircraft men call it angle of attack—to get the maximum life. But the fuselage, the engine cowlings, the juncture of wings and body are nicely smoothed out. All surfaces are well rounded to permit smooth flow of air around them. Even the high-speed planes have the obvious (it seems) needle-like nose and well-tapered bodies to meet the high-speed air streams with least resistance and power loss.

What then all this business about more and bigger wind tunnels? What more can be done? The little black books of the aerodynamicists surely must be filled with air-flow data for every conceivable shape of plane and part, and for all speeds up into the sonic.

The answer from all those who build engines, airplane air-stream components, and airframe builders is a resounding "no." Loudly echoed by those who are working on the frontiers of rockets and guided missiles. Until now, they insist, the problems requiring wind-tunnel solution have been accumulating faster than existing tunnel facilities can provide answers. Furthermore, for certain categories of problems that must be solved before supersonic flight can become common, all the necessary tunnels don't yet exist—although they are on the way.

Flight is becoming more complex by the minute. Most of the new problems rise out of the fact that, as air speeds go up, aerodynamicists are more and more tangling with old man Mach number. Mach 1 is the speed of sound. It is simply a fundamental manifestation of the rate at which pressures or disturbances are transmitted through the atmosphere in question. The rate at which a pressure wave travels through air, i.e., what animals recognize as sound, varies with its temperature. Specifically it is proportional to the square root of the absolute temperature. At 60 degrees F, this rate is about 760 mph; at zero it is 718; and at −67 degrees F it is 663. And this is how altitude gets into the act, because

altitude, per se, hasn't anything to do with Mach number. It is only because the higher the altitude the colder the air. (Above 35,000 feet and up to about 100,000 feet, temperature is pretty generally constant at between 65 and 70 degrees below zero F. Beyond that it warms up.)

Mach Number—At speeds less than sonic, i.e., Mach numbers smaller than unity, the pressure wave moves out in advance of the object, causing the air molecules to begin to evade so that they flow readily around the object when it does arrive. They have a chance to make room in an orderly fashion for the visitor. At Mach 1 or faster, i.e., with the object moving at the same rate or faster than the pressure wave moves, there is no preparation of air molecules for smooth flow. They have no chance to get out of the way, They are struck "broadside." The result is shock, which manifests itself on an airplane as a sudden large increase in drag and serious loss of lift.

One trouble is, however, that this sonic regime is not a sharply narrow speed through which a vehicle can quickly pass—even though violently—to reach the supersonic region where conditions are more stable, somewhat as they are in subsonic flight, but where the cost in propulsise power is terrific. The transition from subsonic to supersonic is a band or zone of speeds. The local rates of air flow about an airplane differ. The air may be moving over some surfaces at Mach 1, while over others it is still less than one. The tips of propellers were the first of aircraft components to get into compressibility-effect difficulty. Thus compressibility effects must be considered in aircraft design for flight speeds of less than sonic. This has brought into being a zone of speeds called the transonic, commonly considered as Mach 0.7 to 1.3.

Likewise air speeds of Mach 1.3 up to about Mach 5 (an arbitrary number) are labeled supersonic, and above Mach 5, the term hypersonic is applied.

It is the transonic and low supersonic regions that today occupy the attention of aircraft people and are the big news in the wind-tunnel field. But that does not obsolete the subsonic test facilities. An airplane can be designed to fly efficiently at supersonic speeds, but it also must be able to land. Thus in take-off and landing it must also fly at subsonic speeds, and to reach top speed must pass through the transonic range. Thin, swept-back wings of small area present many problems in subsonic operation, for which answers can come only via tunnel testing. The countless possible shapes, areas, angle of sweep, and other variables must be explored for their slow-speed performance. Large old tunnels, which produce winds of around 200 mph and were once considered fast, are kept busy on landing and take-off problems that accrue from the new wing and fuselage shapes needed for supersonic flight.

Jet engines have compounded the testing needs. The shape, size, location of air inlets, internal ducts, and exhausts must be explored in infinite detail if maximum use of the available energy is to be made—and in high-speed flight there is no energy to spare.

Adding to the complexity, a small change in jet-engine air intake made to improve engine thrust can disrupt adversely the air flow around certain wing areas or control surfaces. These must be explored; compromises effected. And so on it goes, seemingly without end.

High-speed flight brings with it new problems and greatly intensifies others that can be ignored or easily met

in subsonic flight. Flutter, for example. Higher speed and thinner structural sections used at those speeds cause flutter—which is what a flag does in the wind or a venetian blind will sometimes do in a draft. To show how complex some of these aerodynamic problems become, consider that the problem of flutter of, say, a wing section differs whether the wing fuel tank is full, partially full, or empty.

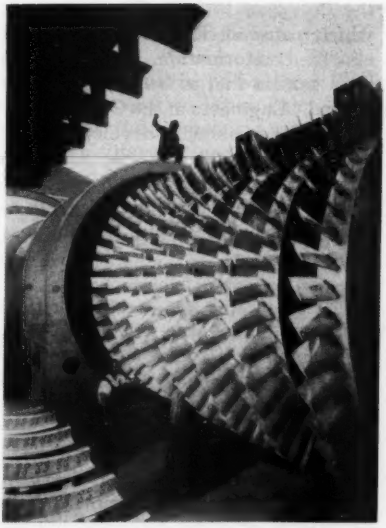
The behavior of control surfaces and of the airplane itself in gusts becomes more critical at higher speeds.

Reynolds Number—Mach number is not the only factor that commands continued obeisance from wind tunnelers. Another is Reynolds number. It is the one that has to do with scale effect. Numerically it is the product of three numbers—air density, relative speed, and length of object, divided by a fourth, the viscosity of the air. These numbers with actual aircraft come large. Reynolds number for a B29 over its normal speed range is 13 to 28 million; for a Thunderbolt fighter plane it is 5 to 20 million. Reynolds number has no quality connotation. The significance of Reynolds number lies in the fact that it expresses the ratio of the pressure forces to the viscous forces for any given flight condition. Reynolds number is important in any model testing because the closer the full-scale value can be approached in the test chamber, the closer is the test to reality and the less the need for undesirable extrapolation.

Since large wind-tunnel test sections and high air speeds simply do not go together, it is possible to test in a wind tunnel an actual airplane or even a sizable section of one at full Reynolds number, only at low speed. Because tunnel test sections are of limited size, scale models must generally be used. The equation shows that Reynolds number can be kept high by increasing the air density. For this reason many tunnels are pumped up to higher pressures. For example, Langley has four pressure tunnels. One is a 19-foot round test section that can be operated at speeds up to 260 mph and 2.3 atmospheres of pressure, and a smaller one with a 3- by 7½-foot section in which tests can be run at air speeds of 350 mph and densities of 10 atmospheres. Also there is a 4-foot supersonic and an 88-foot transonic tunnel.

On the other hand, it is sometimes desired, as with engine components, to make tests under air conditions equivalent to high altitude. Hence some tunnels can be operated under partial vacuum. Lewis Flight Propulsion Laboratory, Cleveland, has such a 500-mph high-altitude tunnel. The Wright Field 10-foot round transonic tunnel can be operated over the range of air densities of 0.12 to 2 atmospheres.

Tunnel Varieties—Various expedients are used to achieve high Mach numbers with a limited power input. One is the intermittent or blow-down tunnel. In one type the air is pumped up to high pressure and stored in a large reservoir. When a test is to be made a quick-acting valve is opened to allow the stored air to rush through the test section at high velocity. In another type a large chamber is evacuated and the air, during the test, is drawn through the test section into it. Sometimes a pressure tank is used on one side and a vacuum chamber on the other. One of these is being erected by the Air Force at the Arnold Engineering Development Center at Tullahoma, Tenn. One exists at Langley Aeronautical Laboratory operating in the speed range of Mach 7 to 10. A blow-down tunnel makes do with less motor horsepower but the time available for a test run is but a few seconds or perhaps a minute or two.



Axial-flow compressor for six- by six-foot supersonic wind tunnel at Ames Aeronautical Laboratory. Power is by two 25,000-hp. motors.

Another way to get a high Mach number without paying the full price of motor horsepower is—as the equations says—change the speed of sound. In Freon 12, because of its greater molecular weight, the speed of sound is but 40 per cent that in air. Thus in a tunnel circuit containing a Freon atmosphere, Mach 1 is achieved at 300 mph instead of 750. Likewise, because density is a factor in the Reynolds equation, use of Freon improves the scale number by a factor of 3.6. Freon, however, introduces complexities of mechanical structure and of data resolution. Freon is used in only a few wind-tunnel installations operating in the high subsonic or transonic speed ranges.

The terms subsonic, transonic, supersonic, and hypersonic are more than just casually useful categories for air speeds. They refer as well to basically different types of wind tunnels. Ordinarily in no practical tunnel can all test conditions be obtained although it could be done with interchangeable tests sections.

This comes about because of the way air behaves at these three conditions. In a subsonic tunnel, the test section is reduced in area compared with the remainder of the tunnel. Air rushing through this restriction speeds up. The greater the restriction or the more horsepower put into the fan the faster the air whistles through the narrowed test zone. Up to Mach 1, that is. When the speed of sound is reached no amount of increase in fan power will increase the air speed at the throat or test section. All the additional power goes into shock losses, i.e., heat. This is called the chokeing effect and is why the transonic tunnel is a special problem that has taken so long to solve. In effect it is because the molecules have become so crowded that they cannot get out of each other's way at a speed above sonic.

Supersonic air speeds can be obtained only in a tunnel that first converges and then diverges, the supersonic speeds occurring in the expanded section—not the smaller section. The air molecules reach sonic velocity—but no more—in the constricted zone. Upon reaching the region of expanding cross section, the air particles can accelerate—and do so at a rate faster than the flow behind them. Given the minimum pressure required to reach sonic speed in the first and narrower throat, the supersonic speed depends only on the expansion rates of the divergence. A supersonic tunnel, therefore, must normally have a separate nozzle for each speed or else an adjustable one of precisely controllable shape.

Subsonic and supersonic tunnels present special operating problems near Mach 1. Between Mach 0.9 and 1.2, either tunnel is so sensitive to small changes in area that a model to be tested, or even disturbances in the tunnel, upset the flow stability.

A solution to this problem of transonic flow was developed at Langley. For it, John Stack, Assistant Director, was awarded the Collier Trophy by the President in 1952. The manner in which transonic flow is obtained is still classified information. All that has been said is that a "ventilated throat is used." Engineers at the Cornell Laboratory have likewise developed a solution in which the principle difference has to do with the openings and the manner of return of the bled air to control turbulence and to minimize power losses.

THE COMPOSITION OF THE WIND-TUNNEL INDUSTRY

There are about 200 wind tunnels in the United States. They range in size of test section from a few square inches to the 40- by 80-foot giant at Ames Laboratory in California, and in power from 1½ hp up to 216,000 hp—not yet completed for Arnold Engineering Development Center at Tullahoma, Tenn. Velocities range from less than 100 mph to about 10,000 mph that can be maintained in a 1- by 4-inch section for a few milliseconds at the Cornell Aeronautical Laboratory at Buffalo.

University Tunnels—Some 17 of the nation's universities have about 30 wind tunnels, almost evenly divided between subsonic and supersonic, with but one transonic. These subsonic tunnels have test sections as large as 12 feet, with air speeds generally in the 125- to 300-mph class and with drive horsepowers of 250 to about 2,500 hp. The scholastic supersonic tunnels have sections as little as 1 by 4 inches and as much as 17 by 20 inches, with a span of Mach numbers from 1.3 to about 5.

University tunnels serve two important functions. The basic one, of course, is classroom instruction. It is from schools so equipped that come the aerodynamically trained men essential to research and testing in the larger laboratories in government and in industry.

Also, important research work is done in university wind tunnels. Much of this is of a fundamental nature, some undertaken on the school's own hook, although some of it is on contract for the Air Force, Navy, NACA, or for private aircraft companies.

Privately Owned Tunnels—Most airframe and engine builders have at least one tunnel. Generally these are subsonic tunnels, with test sections up to 10 or 12 feet. The outstanding example of privately owned facility is the Edmund T. Allen Memorial Laboratory of the Boeing Airplane Company located at Seattle. Their original tunnel was built in 1944 and was powered by an 18,000-hp synchronous motor and eddy-current clutch. It has recently undergone extensive reconstruction consisting in part, of the addition of a 36,000-hp induction motor, making 54,000 in all, and changes in the 8- by 12-foot test section. Speeds up to Mach 1.2 have been attained. This is the largest transonic tunnel in the world owned and operated by a private company.

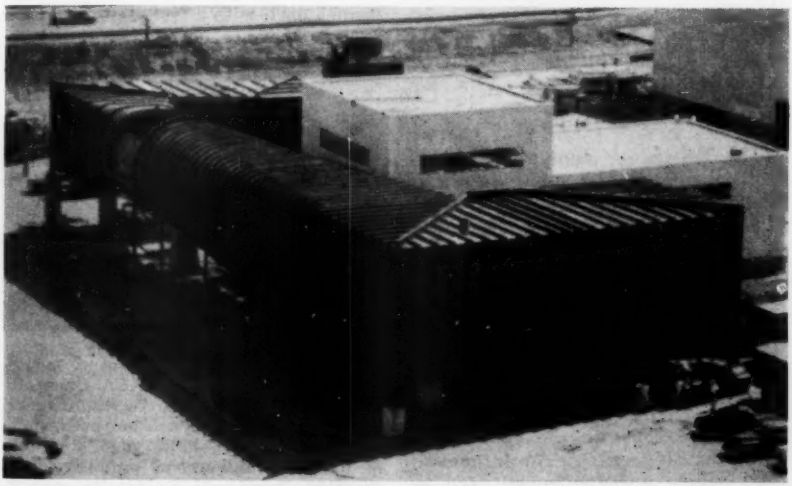
In one case several aircraft compa-

nies have combined resources to provide a cooperative facility that is larger and more flexible than anyone could afford. This is the Southern California Cooperative Wind Tunnel operated for the sponsoring companies by the California Institute of Technology.

Another outstanding research facility is the Cornell Aeronautical Laboratory located near Buffalo. Although owned by Cornell University and administered by it, the laboratory is engaged primarily in work on a contract basis for government and military agencies. The Cornell Laboratory has an 8½- by 12-foot variable-density wind tunnel for operation throughout the subsonic range. The test section has been modified so that it can, at will, be fitted with a 3-by 4-foot transonic test section of a type developed by Cornell engineers and capable of operation over the Mach number range from 0.9 to 1.3. Also it is provided with a propeller dynamometer that makes it possible to apply 2,000 hp to a propeller while operating the tunnel over the transonic range.

The advantages in flexibility and saving in time to manufacturers of having tunnel facilities in their own backyards, or even in a nearby cooperative center, are obviously great. But, because wind tunnels come high in cost, there is a limit to which this can be done—a limit becoming increasingly severe with the growing and doubly difficult need for tunnels of higher Mach numbers and larger test sections.

Government - Owned Tunnels — In addition to the NACA, which we'll return to in a moment, several other branches of the government operate wind tunnels. The Bureau of Standards has two small subsonic tunnels. The Navy has about 15, the largest being a 27,000-hp transonic tunnel at Carderock, Maryland. The Bureau of Ordnance of the Army at Aberdeen, Maryland has two supersonic tunnels of 13,000 hp each.



The McDonnell Aircraft Corporation operates a subsonic tunnel with a 7- by 10-foot test section. Power is supplied by a 1,750 hp. induction motor.

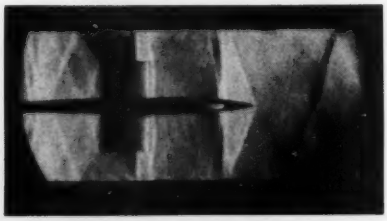
Aside from those of NACA, the largest existing wind-tunnel center is one operated by the Air Force. This is the Wright Air Development Center near Dayton, Ohio. Located there are three subsonic tunnels. Two are small ones, but the third has a 20-foot circular test section and the relatively high subsonic air velocity of 425 mph. This tunnel, built in 1941, is powered by a 40,000-hp motor, which, for ten years, was the largest induction motor in the world. Since the war, a very small transonic and one 10-foot transonic tunnel with a 40,000-hp drive have been added at WADC. Also a 5000 h.p., 2- by 2-foot supersonic and a 1,000-hp, 6- by 6-inch supersonic tunnel have been built recently at Wright Field.

While the wind-tunnel facility and activity at Wright Field is sizable, it is not in the same league with what the Air Force is building at Tullahoma, Tenn. Here on a large tract of Tennessee "barrens" facilities are being erected for aerodynamic testing on an unparalleled scale. This will be the Arnold Engineering Development Center, which is, as is the Wright Field facility, a part of the Air Research and Development Command of the U.S. Air Force.

The Tullahoma plant at the outset will be comprised of three units. The Engine Test Facility will have three test chambers and a test bed in which it will be possible to carry out research, development, and evaluation programs on turbo-jet, turbo-prop, and small ram-jet engines under simulated flight conditions and altitudes up to about 80,000 feet. Temperatures as low as—120 degrees F will be reached. Approximately 75,000 hp is required to operate the compressor and exhauster system. An adjunct to this facility is being constructed in which the largest ram-jet engines now under development can be tested. Much of the equipment in ETF was found operating in Germany during the war and was brought over to this country as reparations. This facility is undergoing its shakedown and calibration runs.

Second of the three major AEDC plants is the Gas Dynamics Facility. It will consist of a group of supersonic wind tunnels for developmental testing of models of aircraft, projectiles, and missiles designed to operate at extremely high speeds; some of these tunnels are to operate at the hypersonic range. The primary air mover is an extremely versatile compressor plant containing six axial compressors and six centrifugal compressors, driven by electric motors totaling almost 100,000 hp. One of the smaller supersonic tunnels has been in operation for several months.

The third and largest operation—largest anywhere in fact—will be the Propulsion Wind Tunnel. It will consist of a transonic and a supersonic tunnel, each with a test section 16 feet square. They are intended for developmental testing of full-scale operating



A Schlieren photograph of a model taken at Mach 1.1 in a NACA transonic tunnel at Langley Field. To record these shock waves on film a beam of light is projected across a knife edge, past the model, and over a second knife edge onto the film. Changes in air density, caused by the shock waves, result in different amounts of light reaching the film.

ram-jet and turbo-jet power plants installed in missiles or aircraft. In addition, propellers and aerodynamic models can be tested. The two tunnels will be arranged so that both can be served by one power plant of 216,000 hp. It is significant of the thinking for the future that space is left for the addition of a 180,000-hp motor to the present four, making available about 400,000 hp to either tunnel.

The NACA—By all odds, the outstanding factor in the wind-tunnel business has been and is the NACA. This important body was established by Congress in 1915 as an agency reporting to the President. While the bulk of its work is obviously of interest first to military aviation, it is not a part of the Armed Forces. As its name states, it is run by a committee —a board of directors would be more descriptive. These 17 men, who serve without pay, are members of the top echelons of science, industry, the Armed Forces, and other government agencies. They are appointed to the committee by the President.

The wind-tunnel activities of NACA (it engages in other aspects of aircraft and guided-missile research) are located at three centers: Langley Aeronautical Laboratory, near Hampton, Virginia; Ames Aeronautical Laboratory at Moffett Field, near San Francisco; and Lewis Flight Propulsion Laboratory, close to Cleveland. Langley is the oldest. Also it is largest both in number and variety of facilities. The first tunnel was built there in 1919. It was a five-foot tunnel capable of only a 100-mph breeze. Since then many specialized tunnels have been erected and new ones are currently being added or rebuilt. Today it resembles the campus of a large university, spread out over several hundred acres of ground, which is part of Langley Field. Its buildings house some 20 different wind tunnels. Many are small, special-purpose tunnels, such as for studies of free-flight models for spin. Largest is the "full-scale" 30 by 60 tunnel where an 8,000-hp motor provides air speeds up to 120 mph. Five supersonic and four transonic tunnels are in operation or under construction. Tops for speed is one capable of Mach numbers up to 10 in a test section one foot square. Powerwise, Langley's largest are two with 60,000-hp drives.

In 1940, NACA established a new center of operations at Moffett Field in California. This is Ames Aeronautical Laboratory, which is now equipped with some nine tunnels particularly suited to high-speed aerodynamics. The largest, physically, is the breath-taking full-scale tunnel with a test section of 40 by 80 feet, large enough to take most pursuit planes and several of the small bombers. The circuit of the air passage is more than half a mile. Powered by six 6,000-hp motors, air speeds in the test section reach 250 mph, very high for so large a test area. Also at Ames is the 6-foot tunnel, which is being repowered by a 110,000-hp motor for transonic operation and a 180,000-hp tunnel (216,000-hp on a half-hour basis) being constructed with two throats. A 6- by 6-foot supersonic tunnel has a 60,000-hp. drive. In addition to several smaller tunnels, Ames has four large tunnels with drives totaling 442,000-hp.

Only slightly younger than Ames is the Lewis Flight Propulsion Laboratory. The principal objective here is engine research. The laboratory is now equipped with four super-sonic tunnels, and other facilities. Its 6- by 8-foot tunnel, capable of Mach number 1.8 with a drive totaling 100,000-hp, is the largest supersonic tunnel now in operation anywhere. A new, larger supersonic tunnel is now under construction at Lewis.

Interrelationship of Tunnel Operation—With so many tunnels of different kinds and sizes operated by different groups, and remembering that wind tunnels are expensive masses of machinery, it is appropriate to ask about the coordination and integration of effort, and the extent of duplication of facilities. There is, indeed, considerable overlap in the abilities of different tunnels. But, let us quickly say, most of this duplication is entirely justified, if not downright essential. In the first place the amount of work to be done is so vast that many tunnels of one class are needed simply to provide the hours required to keep abreast of the load. This will be true as long as we are in an expanding air age—higher speed, manned flight, larger aircraft, guided missiles, rockets, helicopters, new types of power plants, and so on. Until now, at least, the availability of tunnels has seriously lagged behind the need of them. The question at any wind-tunnel center has been, "Which are the most urgent problems?" never, "What can we find to do?" There is work aplenty for all tunnels.

Also engine and airframe builders are scattered over wide areas of the United States. This makes a geographical spread of tunnels highly desirable.

There is no formal, integrating agency by which testing in institutional, industrial, and governmental tunnels is fully coordinated. While undoubtedly there has been some duplication of effort, there is much less of this than one might think.

Actually there is an effective coordination on an informal basis. This is probably better. This ensues because of overlapping committees that direct the work in the government-owned tunnels and the fact that the results of all work done therein are available to those segments of industry entitled to have it. One of the functions of NACA is to coordinate aeronautical research in the United States, an important service it is peculiarly able to perform because of the composition of its governing body. The reports of all unclassified work done become public information. Classified matter is available to all groups working in that area. The NACA group, by informal means, is kept well advised of work done in other laboratories, even to a large extent those of industry. To collect material for this article, the author visited many of the aerodynamic research and development centers of government and industry. We were impressed by the awareness in each group of what other groups are doing and the obvious desire among the aerodynamic research fraternity to avoid unnecessary duplication of effort.

Early in War II, a fundamental high-level decision was made in Washington—that all hands had best join in the immediate job of providing airplanes of a quality that would help win the war. NACA turned to the more immediate problems of airplane development, to help solve the troubles as they appeared with prototype planes, and to help better the performance of production models.

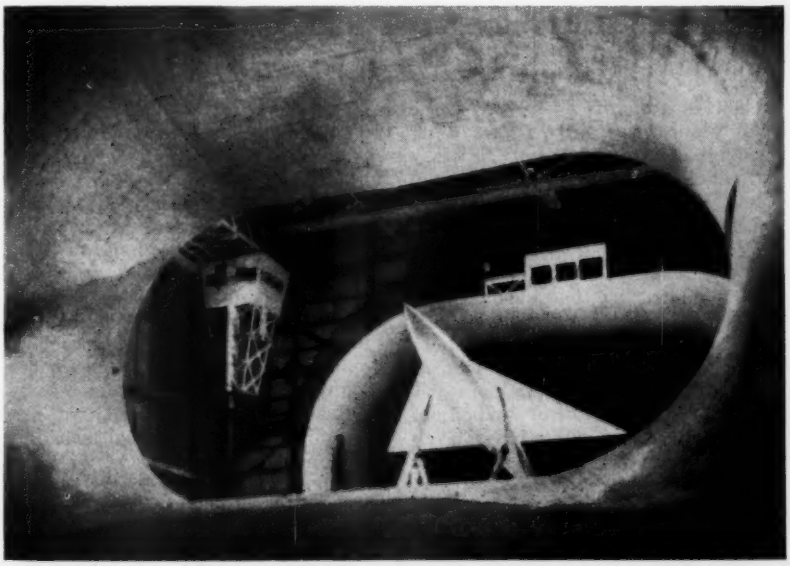
Thus there was, during World War II, an almost complete moratorium on fundamental aerodynamic research. Of necessity, work done on guided missiles, rockets, and the like suffered until after V-J Day. This resulted in the sentiment one finds expressed in many quarters of industry and government, of a post-war shortage of fundamental aerodynamic knowledge. Practice is currently riding too hard on the heels of theory. This in large part lies behind the present expansion program for the modification of old tunnels and construction of new types capable of conducting research in the new fields.

Much catching up in knowledge of flight is in order.

With basic research falling primarily to the lot of NACA, and to some extent to universities, development of specific components and planes becomes the primary concern of industry and of the Armed Forces. Thus the big centralized laboratories, primarily of the Air Force, are aimed at providing development facilities on a scale no private company can justify and at furnishing means for evaluating the constructions provided on contract by industry.

With this general concept of tunnel function in mind, the NACA, Air Force, and Navy took action in 1946. They took note at war's end of major lacks in this country's aerodynamic research and development facilities. Thus the Unitary Plan was formulated. This took into account existing university, industry, and government facilities and set forth the additional plant visualized as necessary for the next ten years. As originally set down, the plan was comprehensive and very expensive. It has since been abbreviated. However, the final Unitary Plan now being materialized does call for the construction of specific tunnels by NACA, the Air Force, and the Navy. Most of these are finished or under way. The Tullahoma project is one.

The Justification for Wind Tunnels —Wind tunnels are man's largest precision instruments. They are expensive to build and to run. But, as one man, experienced in the aviation field, has said, "Sure they are costly, but not nearly as expensive as trying to get along without them. Just think what it costs to build 1,000 planes of the wrong kind. In a war, that can happen."



A model in the Langley Aeronautical Laboratory full-scale wind tunnel.

Wind tunnels are great time savers. In a modern or a future war even a few days' time may be without price. Flight testing will, of course, always be necessary, but it can be greatly reduced by adequate work done in tunnels long before the prototype aircraft are wheeled onto the runway. Flight testing is expensive, too, not only in dollars but in pilots' lives. And wind tunnels give the indispensable opportunity to test components or scale models with a succession of modifications, changing one variable at a time, all under controlled conditions with the ability to make precise measurements.

A modern military plane will go through five to ten models before it becomes obsolete. Each is more easily controlled, is more maneuverable, is faster, is able to fly farther on a given amount of fuel, or in other ways is better able to do the job than its predecessor. Much if not most of each improvement comes from what is learned about it in the laboratory.

Planes are flying faster, higher, and longer, and have new types of power plants. They are becoming so complex that to design a plane or missile or rocket from wholly fundamental considerations is hopeless. An NACA publication of a year ago succinctly stated the situation thusly: "We have yet to learn the extent to which detailed information about one specific design can be successfully applied to other designs." The airplane of today and, even more so, the airplane of tomorrow is designed in the wind tunnel.

THE SPECIFIC SPEED METHOD OF PROPULSIVE ANALYSIS

S. E. SLOCUM
Hon. Life Mem. A.S.N.E.

THE AUTHOR

B.E., Union College, Schenectady, N.Y.; Ph.D. in mathematics and physics, in course, Clark University, Worcester, Mass.; Professor of applied mathematics, University of Cincinnati and University of Illinois; specialist in marine propulsion in private practice since 1922. First to introduce modern streamline propeller design in the U. S.; author of "Practical Application of Modern Hydrodynamics to Marine Propulsion," 1927, for which he was awarded the Gold Medal of the American Society of Naval Engineers, and life membership in the Society. Engaged in commercial propulsive practice since 1922. Also author of numerous books and articles on other subjects.

The problem of ship propulsion consists in the proper coordination of hull, power plant and propeller, in which the latter is the coordinating element. The usual method consists in combining certain quantities, often quite unrelated, with no overall criterion by which the final combination may be represented. The simple function called the specific speed provides a type characteristic which uniquely represents the performance of any given combination of hull, power plant and propeller, independent of scale or empirical factors. Any change in propeller dimensions, such as diameter or pitch, alters the value of the specific speed. In other words, the specific speed provides a simple criterion for the overall performance of any given vessel. It may also be used as the basis for a complete rational and scientific system of propeller design.

The method of specific speed has been found very useful in the classification of hydraulic turbines. The idea of specific speed was originated by Professor Cammerer of Munich, and seems to have been first applied to turbine practice by N. Bashuus of Toronto, Canada, about 1912. This new method of turbine classification was developed by the writer in his HYDRAULICS published in 1915*; and in 1916, M. S. Stuart applied the specific speed method to centrifugal fans, and in 1918 to aircraft propellers.** In 1921 Dr. Baumann published a tabulation of specific speeds for various

*Hydraulics, McGraw-Hill, N.Y., 1915; pp 202-214.
**M. S. Stuart, Jour. A.S.N.E., vol. XXX, No. 2, May 1918; p 315.

types of machines. About the same time Mr. Lewis F. Moody developed the propeller type of hydraulic turbine, and in an article published in 1922, suggested that marine propellers might be regarded as in the same class as this new type of turbine. In 1930 the writer applied the specific speed method to standardization of ship performance, and also developed a complete system of propeller design based entirely on specific speed.

For an hydraulic turbine, the specific speed is a single non-dimensional parameter, which is a function of the head on the runner, its speed of rotation, and the power developed. Since the head on the runner is constant, it works under uniform conditions, and the specific speed is a single quantity. For marine propellers the problem is more complex and requires five such parameters. However, only two of these are required for standardization of ship performance, and three for a complete system of propeller design. In other words, two of the five are redundant.

In the writer's monograph which developed the basic formulas for circulation type propellers, the integrals for propeller thrust, T, and torsional moment, M, were;*

$$\frac{T}{GV^2D^2}=K_1\beta nS\,\frac{DN}{V}\left(a_1\frac{DN}{V}-a_2\lambda\beta\right)$$

$$\frac{M}{GV^2D^3}=K_2\beta nS\,\frac{DN}{V}\left(b_1\lambda\beta\frac{DN}{V}+b_2\right)$$

where D denotes propeller diameter, S is a blade parameter which determines its size, n is the number of blades, N is propeller speed, G is the kinematic viscosity of water, V is the speed of advance through the wake, λ, $\lambda\beta$ are blade angles, K_1, K_2 are constants covering hydraulic losses, and a_1, a_2, b_1, b_2 are numerical constants of integration. Combining constants, these relations may be simplified into

$$\frac{T}{V^2D^2}=m\left(\frac{DN}{V}\right)^2+p\frac{DN}{V}$$

$$\frac{M}{V^2D^3}=n\left(\frac{DN}{V}\right)^2+q\frac{DN}{V}$$

By shifting the origin of coordinates, the linear terms can be made to vanish; and these relations further simplify into the following:

$$\frac{T}{V^2D^2}=m\left(\frac{DN}{V}\right)^2;\quad \frac{M}{V^2D^3}=n\left(\frac{DN}{V}\right)^2$$

These equations are non-dimensional, and independent of scale, or system of units used.

It is convenient to express the thrust, T, and torsional moment, M, in these equations in terms of the thrust horsepower, T.H.P., and shaft horsepower, S.H.P., by means of the relations,

$$T=\frac{550\ \text{T.H.P.}}{V};\quad M=\frac{63030\ \text{S.H.P.}}{N}$$

Substituting these values, we have

$$\text{T.H.P.}=\frac{n}{550}D^4N^2V$$

$$\text{S.H.P.}=\frac{m}{63030}D^5N^3$$

Since DN is proportional to V, write DN/V = c. Then in terms of c, we have

$$D^5N^3=\frac{c^4V^5}{N^2};\quad D^4N^2V=\frac{c^4V^5}{N^2}$$

and therefore the expressions for horsepower may be written,

$$\text{T.H.P.}=\frac{nc^4}{550}\frac{V^5}{N^2};\quad \text{S.H.P.}=\frac{mc^5}{63030}\frac{V^5}{N^2}$$

The constant term in these relations will be replaced by a single parameter.

*Practical Application of Modern Hydrodynamics to Marine Propulsion; Jour. A.S.N.E., vol. XXX, No. 1, Feb. 1927; Equa. 99, p. 30.

which for reasons which will appear shortly, it is convenient to denote by N^2_{ST} for thrust horsepower, and N^2_{SP} for shaft horsepower. In this notation, the expressions become

$$T.H.P. = N^2_{ST}\frac{V^5}{N^2}; \quad S.H.P. = N^2_{SP}\frac{V^5}{N^2}$$

whence

$$(1) \quad \boxed{N_{ST} = \frac{N(T.H.P.)^{1/2}}{V^{5/2}}}$$

$$(2) \quad \boxed{N_{SP} = \frac{N(S.H.P.)^{1/2}}{V^{5/2}}}$$

These parameters are the *SPECIFIC SPEEDS* for power; N_{ST} in terms of thrust horsepower, and N_{SP} in terms of shaft horsepower.

When T.H.D. = 1 and V = 1, then $N_{ST} = N$. Therefore the specific speed for thrust horsepower is the actual speed of rotation of a propeller of given dimensions when reduced in scale to the point where it absorbs one thrust horsepower when advancing through the wake with a speed of one foot per second.

When S.H.P. = 1 and V = 1, then $N_{SP} = N$. Therefore the specific speed for shaft horsepower is the actual speed of a propeller of given dimensions when reduced in scale to such an extent that it absorbs one shaft horsepower when advancing through the wake with a speed of one foot per second.

In deriving these expressions, the diameter, D, was eliminated. Similar expressions in terms of D may be obtained by eliminating N. For this purpose, return to the expressions for S.H.P. and T.H.P., and use the proportionality to eliminate N. The result of this substitution is,

$$T.H.P. = \frac{c^2 n}{550} D^2 V^3$$

$$S.H.P. = \frac{m\, c^3}{63030} D^2 V^3$$

Denote the constant terms in these expressions by D^2_{TD} and D^2_{PD} respectively; then they become,

$$T.H.P. = D^2_{TD}\, D^2 V^3$$
$$S.H.P. = D^2_{PD}\, D^2 V^3$$

whence

$$(3) \quad \boxed{D_{TD} = \frac{D\, V^{3/2}}{(T.H.P.)^{1/2}}}$$

$$(4) \quad \boxed{D_{PD} = \frac{D\, V^{3/2}}{(S.H.P.)^{1/2}}}$$

These parameters, D_{TD} and D_{PD}, are called SPECIFIC DIAMETERS.

If T.H.P. = 1 and V = 1, then V_{TD} = D. Similarly if S.H.P. = 1 and V = 1, then D_{PD} = D; therefore the specific diameter is the actual diameter of a propeller of given dimensions reduced in scale to such an extent it absorbs horsepower (T.H.P. or S.H.P.) when advancing through the wake with a speed of one unit per second.

A fifth relation is required to complete the system of specific parameters. To derive this parameter, let v denote the peripheral tip speed of a propeller of diameter D rotating at N revolutions per minute. Then $v = \pi DN$. Now let v_t denote the specific tip speed; then by definition it must represent the actual tip speed of a propeller of specific diameter D_{TD} (or D_{PD}) rotating at a specific speed of N_{ST} (or N_{SP}). Consequently

$$v_t = \pi\, D_{TD}\, N_{TD} = \pi\, D_{PD}\, N_{PD}$$

Substituting the values of the specific

parameters, we have the SPECIFIC TIP SPEED,

$$(5) \quad \boxed{v_t = \frac{\pi DN}{V} = \frac{v}{V}}$$

These specific parameters are non-dimensional; however, in practice, V may be used in knots without reducing it to feet per minute, as we are not concerned with the absolute value of these expressions, as will appear in the numerical applications which follow.

These five parameters, (1) to (5), completely characterize propeller performance. Each combination of hull, power plant and propeller gives rise to a set of numerical values of these parameters; conversely, each set of numerical values of these parameters, uniquely defines the performance of the vessel. For purposes of analysis and design, two of these five parameters are redundant. If the shaft horsepower is given, parameters (2), (4) and (5) are sufficient for solution of the problem. If the E.H.P., or tow-rope horsepower, is given, parameters (1), (3) and (5) are sufficient.

These five parameters are all non-dimensional. Therefore they are independent of scale, and represent the performance either of ship or model, provided only that geometrical similarity is maintained. This makes it possible to step-up model tests directly to full scale performance, as illustrated in what follows.

The specific speed defined by parameter (2) has been noted by others, although as an independent quantity, and has not been applied to propeller design or analysis of performance, as developed in what follows. Parameter (2) was called by Schaffran the "revolution-torque constant"; it is also identical with the quantity which Admiral D. W. Taylor, U.S.N., called the "B variable," or "basic variable B_p." As mentioned in what precedes, it has also been applied by Stuart to centrifugal fans, and to aircraft propellers, but there has been no application of these parameters to marine practice. They are here shown to be derivatives of the fundamental integral relations for propeller action, derived by rigorous mathematical analysis based on hydrodynamical laws; and that they fulfill the requirement of being both necessary and sufficient for a complete description of propeller action. Also exemplified in what follows is their practical use in standardizing ship performance, and for coordinating model test data with full scale ship performance.

In 1929, about the time the writer was developing this method of specific parameters, the U. S. Shipping Board was standardizing a merchant ship, Hull 1037, named the CLAIRTON. This was a merchant ship, 395′ B.P.x55′ beam x 27′ draft; displacement at draft 13,140 tons; 2400 shaft horsepower at 90 revolutions per minute, with four-blade propeller 17′ diameter of Shipping Board design. This vessel was standardized on the Rockland course, and its model was tested in the Washington Model Basin. In the March, 1930, issue of Marine Engineering, the comparative results of these tests were presented by the late R. R. Adams, who had conducted them, and had recently left the Shipping Board to become associated with Grace Lines. By courtesy of Admiral D. W. Taylor, U.S.N., and the U. S. Shipping Board, the complete data from these tests were furnished the writer to illustrate the application of the specific parameter method for standardizing performance. It is seldom that such complete data are available, and they form a valuable

criterion for exemplifying the specific speed method of analysis.

Since the specific parameters are non-dimensional, any convenient units may be used in their application. For the ship standardization trials the units chosen will be speed in knots, propeller revolutions per minute, and shaft horsepower. For example, for a ship speed of 7 knots, propeller speed of 54 R.P.M. and 560 S.H.P., we have

$$N_{SP}=\frac{54\sqrt{560}}{7^{5/2}}=9.857$$

$$v_S=\frac{\pi\times17\times54}{7}=412.0$$

Following this example, the specific speeds calculated from the trial data are shown in the following table.

TABLE 1

Standardization trials of S/S CLAIRTON.						
Speed in knots	R.P.M.	S.H.P.	N_{SP}	Var. from mean	v_t	Var. from mean
7	54	560	9.857	−1.3%	412.0	0.0
8	62	810	9.748	0.2%	413.9	+0.4%
9	69	1140	9.587	−1.4%	409.5	−0.6%
10	77	1560	9.617	−1.1%	411.2	−0.2%
11	85	2100	9.706	−0.2%	412.7	+0.1%
12	93	2780	9.830	1.1%	413.9	+0.4%
			Mean		Mean	
			9.724		412.2	

In this analysis, note first that the specific tip speed, v_t is practically constant, its maximum variation from the arithmetic mean being only six-tenths one one percent. Note second, that the specific speed, N_{SP}, is also substantially constant, its variation from the arithmetic mean being so small as to be well within the limits of errors of observation.

It can be easily shown that the following relation exists between these two parameters: $N_{SP}=\text{Constant} \times v_t^{5/2}$ Therefore if the specific tip speed is constant, the specific speed for power must also be constant. Therefore a single pair of values of these parameters is sufficient to determine the entire performance of the vessel. Exceptions to this rule may occur in the case of propellers in cavitation, or overloaded, or of small diameter and abnormally high speed.

These parameters will now be calculated from the Model Basin self propelled tests on the model of the S/S CLAIRTON, as shown in the following table.

A comparison of these two tables shows that the variation of individual values of these parameters from the arithmetic mean is greater for the tank

TABLE 2

SS CLAIRTON Self propelled model test data				Specific speeds			
No. run	Speed knots	R.P.M.	S.H.P.	N_{SP}	Var. from mean in percent	v_t	Var. from mean in percent
1	1.600	247.4	.01562	9.548	+ 4.7	417.5	+1.9
2	1.693	252.9	.01632	8.665	− 5.0	403.5	−1.5
3	1.848	270.7	.01946	8.136	−10.8	395.7	−3.4
4	2.000	289.2	.02371	7.872	−13.6	390.5	−4.7
5	1.994	298.3	.02657	8.661	− 5.0	404.0	−1.4
6	2.072	312.3	.03143	8.958	− 1.7	407.0	−0.6
7	2.158	327.6	.03572	9.050	− 0.7	410.0	+0.07
8	2.312	339.4	.03940	8.289	− 9.1	396.5	−3.8
9	2.308	354.1	.14656	9.440	+ 3.5	414.3	+1.1
10	2.488	370.2	.05134	8.591	− 5.8	401.9	−1.9
11	2.485	371.3	.05235	8.726	− 4.3	403.5	−1.5
12	2.505	388.5	.06154	9.704	+ 6.4	418.9	+2.2
13	2.660	413.1	.07319	9.684	+ 6.2	419.4	+2.3
14	2.740	419.2	.07715	9.370	+ 2.7	413.2	+0.8
15	2.865	432.6	.08340	8.993	− 1.4	407.8	−0.4
16	2.835	436.0	.08792	9.554	+ 4.8	415.4	+1.4
17	2.933	457.3	.10300	9.963	+ 9.2	421.1	+2.8
18	3.005	472.4	.11450	10.210	+11.9	424.6	+3.6
19	3.027	469.8	.11180	9.855	+ 8.7	419.1	+2.3
				Mean 9.119	Average 6.08%	Mean 409.7	Average 1.95%

tests than for full scale standardization. This is chiefly due to the fact that the model tank readings are so small that it is impossible to observe them with the same degree of accuracy as the full scale readings on the ship. Also in tank tests the readings at the beginning of a trial are so small that the instrumental errors are greater than near the end of the trial when the readings are greater. To illustrate this point, consider only the last six runs, 14 to 19, of the trial data, and determine the mean values of the specific speeds from these larger readings, and the variation from the mean, as shown in the following table:

TABLE 3

No. of run	N_{SP}	Variation from mean in percent	v_t	Variation from mean in percent
14	9.370	−3.0	413.2	−0.8
15	8.993	−6.8	407.8	−2.2
16	9.554	−1.1	415.4	−0.3
17	9.863	+3.1	421.1	+1.0
18	10.210	+5.7	424.6	+1.8
19	9.885	+2.0	419.1	+0.5
	Mean 9.657	Average 3.6	Mean 416.9	Average 1.1

The variation of these two specific parameters from their mean values gives a reliable indication of the relative accuracy of the test data. Furthermore, the ordinary method of presenting test data by plotting each observed value and fairing the results with a spline, introduces a personal error of judgement; whereas the specific speed method fairs the data mathematically in accordance with the law of probability, and is free from the personal equation.

There is another important feature in which the specific speed method of analysis is superior to ordinary methods of handling test data, based on the laws of dynamical similarity. One of the results of the SS CLAIRTON tests was to show the rather wide difference in predicted performance as determined by the principle of dynamical similarity and actual performance over the measured mile. As the result of this observed difference, empirical corrections are now introduced before the tank test data are scaled up to predicted performance. The test results on the CLAIRTON,* together with the results of applying the specific speed method of analysis, are shown in the accompanying figure. From Table 2 the specific tip speed as determined from the entire series of 19 test runs is $v_t = 409.7$. Since $v_t = \frac{DN}{V}$ we have $409.7 = \frac{17N}{V}$ from which N is computed for various values of V, and from these pairs of values, the speed-revolutions graph is plotted. Similarly from Table 2 the mean value of the specific speed N_{SP} is 9.119. Therefore

$$9.119 = \frac{N\ (S.H.P.)^{\frac{1}{2}}}{V^{5/2}}$$

Substituting in this relation corresponding pairs of values of N and V determined from the specific tip speed, v_t, the shaft horsepower is determined. The predicted performance of the CLAIRTON as determined from these values is shown on the left side of Table 4.

If we use the more accurate values of the specific speeds, obtained from the last six runs in Table 2, namely $v_t = 416.9$, $N_{SP} = 9.657$, the predicted performance will be as shown on the right side of Table 4.

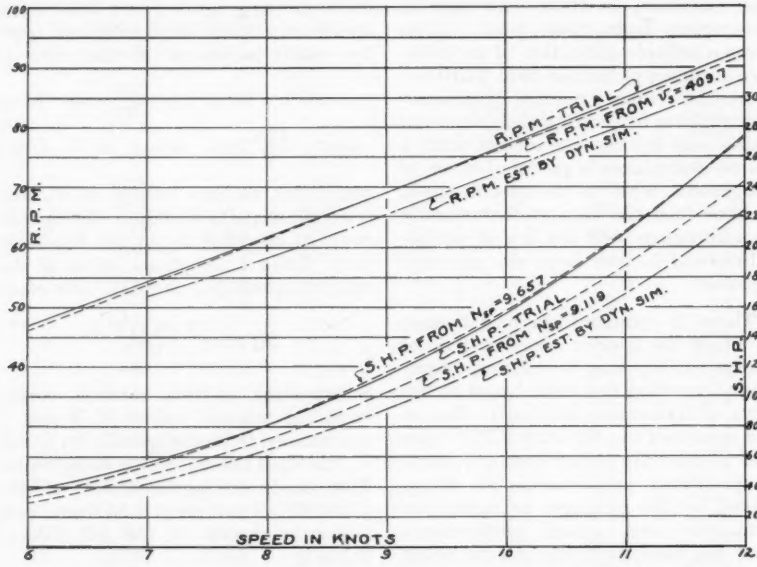
TABLE 4

Predicted performance of SS CLAIRTON based on specific speed method.

Mean of 19 runs $v_t = 409.7$ $N_{SP} = 9.119$			Mean of last 6 runs $v_t = 416.9$ $N_{SP} = 9.657$	
Speed in knots	R.P.M.	S.H.P.	R.P.M.	S.H.P.
6	46.03	305.2	46.84	342.2
7	53.70	484.7	54.64	543.5
8	61.37	723.5	62.45	811.3
9	69.04	1030	70.25	1155
10	76.71	1413	78.06	1585
11	84.38	1881	85.87	2109
12	92.06	2442	93.67	2738

This predicted performance, together with the actual performance over the measured mile and performance based on dynamical similarity, as given in Mr. Adams report, are shown graphically on the accompanying chart (Fig. 2). This shows that the specific speed method of analysis affords an accurate and scientific means for the control of test data, which eliminates the person-

*Marine Engr. & Ship. Age, Mar., 1930 and Dec., 1930.

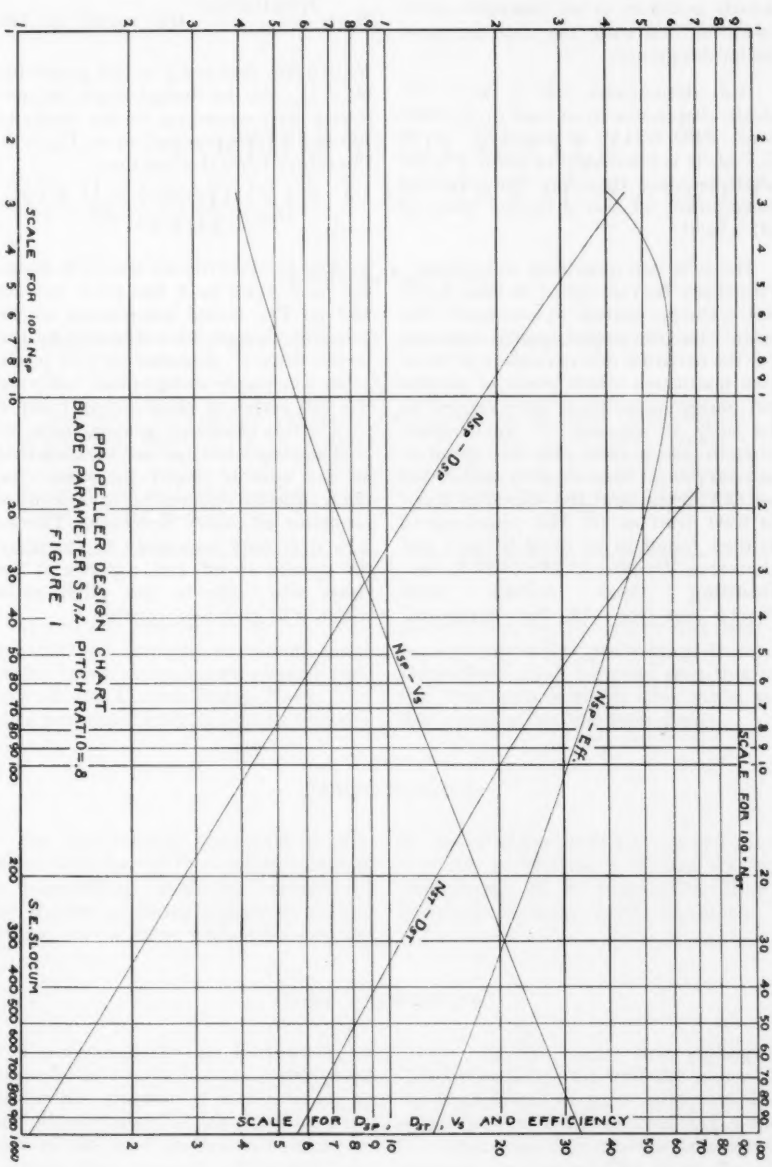


COMPARISON OF ESTIMATED AND ACTUAL PERFORMANCE S/S CLAIRTON

al equation entirely, and is substantially equivalent to the least square method of adjusting observations. The special advantage of the specific speed function is that it provides a single numerical value which constitutes a type characteristic by which the given combination of hull and propeller may be classified. Any change in propeller dimensions, such as change in diameter or pitch, alters the type characteristic represented numerically by the specific speed. In other words, the specific speed gives an overall picture of the performance of any given combination of hull and propeller, independent of scale or empirical factors.

A complete propeller design chart may be laid out in terms of these five parameters by using the specific speeds N_{SP} and N_{ST} as base, and the other parameters as ordinates. For this purpose it is convenient to use double scale logarithmic paper, as the graphs are then approximately straight lines. A set of such graphs for a single pitch ratio is shown on the accompanying sample propeller design chart (Fig. 1). In the layout of this chart, all quantities are expressed in feet and second units except horsepower, which is not altered. The result is that the numerical value of the calculated specific speeds are decimals, and therefore they are plotted as 100 N_{SP} and 100 N_{ST} respectively, as indicated. The single set of graphs shown is for a four blade propeller, of pitch ratio .8, and developed area ratio of about .425. A complete chart of this type consists of a family of parallel graphs, which by reason of the scale chosen, do not overlap, and therefore a complete design chart may be represented on a single sheet without confusion.

The graph here shown is chosen for illustration because it fits the propeller designed for the SS CLAIRTON,


PROPELLER DESIGN CHART
BLADE PARAMETER S=7.2 PITCH RATIO=.8
FIGURE 1
S.E. SLOCUM
SCALE FOR 100 ÷ N_{SP}
SCALE FOR 100 ÷ N_{ST}
SCALE FOR D_{SP}, D_{ST}, V_S AND EFFICIENCY
N_{SP} – D_{SP}
N_{SP} – V_S
N_{SP} – EFF.
N_{ST} – D_{ST}

which is taken as an example of its use. For this ship, the data for propeller design are;

Hull dimensions, 395′ x 55′ x 20′ draft; displacement at load draft, 9390 tons; 2400 S.H.P. at coupling, at 90 R.P.M. It is necessary to allow 3% for shaft friction; therefore the effective horsepower at the propeller will be .97 x 2400.

The first two quantities to be determined are service speed at load draft; and wake percentage at load draft. The writer has developed special methods for the accurate determination of these two quantities which years of practical design experience have proved to be fully as accurate as model tank tests. In the present case the speed in sea service at load draft is calculated as 12.5 knots; and the effective wake at load draft as .32. The vessel speed is then found to be 21.12 ft./sec., and therefore V=.68 x 21.12=14.36 ft./sec. Inserting these values, with N=1.5 rev./sec., in the parameter $N_{SP}=\frac{N(S.H.P.)^{1/2}}{V^{5/2}}$ the result is, 100 $N_{SP}=9.269$. Referring to the graph for $N_{SP}-D_{SP}$ on the design chart, the ordinate corresponding to the abscissa 100 $N_{SP}=9.269$ is found to be $D_{SP}=19$. Therefore from the relation

$$D_{SP}=\frac{D\,V^{5/2}}{(S.H.P.)^{1/2}}=19$$

we find D=16.9 ft. Call this 17 ft. Since the pitch ratio is .8, the pitch will be 13.6 ft. The actual dimensions of the propeller designed for this ship by the writer were 17′ diameter by 13.5′ pitch.

On a complete design chart covering the full series of pitch ratios, from .6 to 1.5, the efficiency graphs form an overlapping family of curves, such that as the specific speed increases, the pitch ratio corresponding to maximum propeller efficiency decreases. Therefore it is only necessary to calculate the specific speed, and a glance at the chart will indicate the pitch ratio which will give best results.

MAKE-UP FEED WATER REQUIREMENTS FOR NAVAL VESSELS

LESLIE E. ALSAGER

THE AUTHOR

is a native of Minneapolis, Minnesota. He received the Bachelor of Mechanical Engineering degree from the University of Minnesota in 1949 and became a Registered Professional Engineer in that state. Shortly thereafter during 1949 he became a civilian engineer in the Bureau of Ships. For the past three years he has been a Marine Engineer with the Scientific Section of the Machinery Branch of the Bureau.

The article interprets the results of a statistical analysis of steam plant water losses encountered aboard vessels of the United States Navy. The data presented summarizes an investigation made by the author and incorporated into a Bureau of Ships Design Data Sheet. It is believed that this is the first such analysis ever given to this phase of marine plant design.

ACKNOWLEDGEMENT

The information contained in this paper was derived from a large amount of painstaking calculation carried out by Bureau of Ships engineers. At the outset the author wishes to express his indebtedness to this group and particularly to Messrs. R. Michel, G. M. Boatwright, M. R. Hauschildt, H. F. Smith, M. Welling, and T. McIntosh.

MAKE-UP FEED WATER

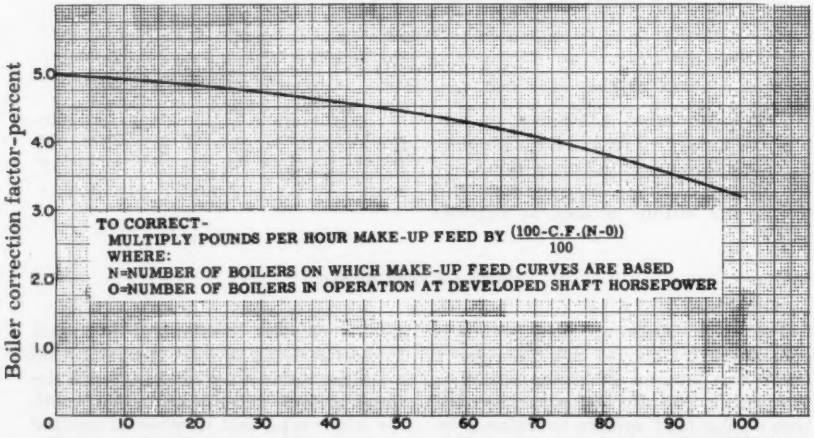
The term make-up feed water is considered by marine plant designers to be the amount of water which is introduced into the low pressure portion of the feed system to balance or replace the amount of water lost through blowdowns, soot blowers, steam whistles, vents and leakages. Understandably, the amount required for these losses vary not only with the ship's power requirements but with the kind, type and number of related pieces of equipment. The losses due to blowdowns and soot blowers can

usually be predicted with a fair degree of accuracy, but the other, the miscellaneous losses, are naturally indefinite. Because of these indefinite losses an extensive analysis was necessary to predict within engineering accuracy the total losses. Water washdown of the boiler firesides and boiler watersides were not included in the calculations and analysis on the theory that it is not directly chargeable to the plant cycle.

SCOPE OF THE DATA

The equations and curve contained in this paper were formulated upon averages of 2100 monthly reports for 186 ships which were in underway operation at least 350 hours in one month. Hundreds of reports of vessels in operation less than 350 hours in any one month were used to get the data for low load plant operation. Each of these monthly reports as submitted by the ship to the Bureau of Ships contain hours of underway ship speed for the month. In order to formulate satisfactory engineering data it was considered that only reports which indicated underway ship time of more than 350 hours per month should be used to determine the water requirements. However, to completely and fairly analyze the ship's usage all low speed-low operating time reports had to be evaluated. The low speed-low operating time data were used to determine the water requirements at anchor condition.

During the leveling and interpretation of the data the author realized that some significance had to be placed on the individual power plant details of each ship. It was also realized that if the ship designer was to be able to use the data in the preliminary ship design stage, he must have it in terms of variables readily available and applicable to the design. Interpretation of the data must also be given in such a way that it could be used for ship conversion as well as for new construction. To this end the author decided to use the turbine steam rate and shaft horsepower of the vessel as the basis of the



Percent of full power shaft horsepower correction curve for number of boilers per shaft.

developed equations and curve. The steam rate for the groups of vessels studied is an indication of the age, pressure and temperatures of the ship's power plants. The design shaft horsepower is an indication of the sizes of the steam plant. To get part-load operation, a third variable of developed shaft horsepower was introduced. Under the criterion of making this very complex problem relatively simple one other variable had to be introduced. This variable, the boiler use factor, made it possible to level the data by types of Naval vessels. The use of this factor is empirical insofar as the data are concerned, but has been corroborated by boiler design personnel and was indicated in the collected data. Future data will be used to evaluate this factor.

EQUATIONS

Equations for determination of make-up feed requirements are as follows:

(a) Steam rate equals

Steam consumption divided by shaft horsepower

$$SR = \frac{SC}{(SHP)_d}$$

(b) Make-up feed equations

(1) Destroyer Escorts (Based on one boiler per shaft)

$$MUF = BC\ ((0.0072 \times SR \times (SHP)_d \text{ per shaft}) + (0.0798\ (SHP)_{fp} \text{ per shaft}))$$

(2) Destroyers (Based on two boilers per shaft)

$$MUF = BC\ ((0.00320 \times SR \times (SHP)_d \text{ per shaft}) + (0.02298\ (SHP)_{fp} \text{ per shaft}))$$

(3) Cruisers (Based on one boiler per shaft)

$$MUF = BC\ ((0.00280 \times SR \times (SHP)_d \text{ per shaft}) + (0.0281\ (SHP)_{fp} \text{ per shaft}))$$

(4) Carriers (Based on two boilers per shaft)

$$MUF = BC\ ((0.00312 \times SR \times (SHP)_d \text{ per shaft}) + (0.03114\ (SHP)_{fp} \text{ per shaft}))$$

(5) Battleships (Based on two boilers per shaft)

$$MUF = BC\ ((0.002776 \times SR \times (SHP)_d \text{ per shaft}) + (0.0244\ (SHP)_{fp} \text{ per shaft}))$$

(c) Boiler use coefficient

$$BC = \frac{100\text{-}CF\ (N\text{-}O)}{100}$$

NOMENCLATURE

BC—Boiler use coefficient.

CF—Boiler correction factor, percent, from curve.

Developed shaft horsepower—Shaft horsepower at which make-up feed is required.

Full power shaft horsepower—Design full power shaft horsepower.

MUF—Make-up feed, pounds per hour per shaft.

N—Number of boilers per shaft on which make-up feed equations are based.

O—Number of boilers per shaft in operation at developed shaft horsepower.

SC—Turbine nonbleed steam consumption at developed shaft horsepower, pounds per shaft.

$(SHP)_d$—Shaft horsepower, developed per shaft.

$(SHP)_{fp}$—Shaft horsepower at full power per shaft.

SR—Steam rate of turbine at developed shaft horsepower, pounds per shaft horsepower-hour.

EXAMPLE OF THE USE OF EQUATIONS

In order to clarify the mechanics of solution of the equation the following example of an assumed problem is given:

Given: Carrier design of 150,000 shaft horsepower total per ship. Ship has 12 boilers in operation and 4 shafts.

Problem: To find make-up feed requirements at 84,000 SHP with a turbine steam consumption of 584,640 pounds per hour per ship.

Solution: $SR = \frac{584,640}{84,000} = 6.96$ pounds per SHP-hour

$$(SHP)_{fp} \text{ per shaft} = \frac{150,000}{4} = 37,500$$

$$(SHP)_d \text{ per shaft} = \frac{84,000}{4} = 21,000$$

Percent of full power shaft horsepower

$\frac{21,000}{37,500} \times 100 = 56$ per cent

From equation for carriers—

MUF = BC ((0.00312 x SR x $(SHP)_d$ per shaft) + (0.03114 (37,500) = BC (1,624 pounds per hour per shaft))

Correction for boilers—CF from curve

$$BC = \frac{100 - CF \times (N-O)}{100}$$

$$MUF = 1,624 \left(\frac{100 - CF \times (N-O)}{100} \right)$$

$$MUF = 1,624 \left(\frac{100 - 4.37(2-3)}{100} \right) = 1,694 \text{ pounds per hour}$$

Since there are four shafts per ship:

Total make-up feed requirements per ship

$= 1,694 \times 4 = 6,776$ pounds per hour or $\frac{6,776}{8.33} = 813.4$ gallons per hour

CONCLUSIONS

It is realized that the data as submitted here are lacking in detail. However, it will be obvious to the power plant engineer that when one considers the vast amount of operating variables, a solution such as this is practical. The equations are based upon averages and should be treated as such and some engineering judgment should be used in applying the principles. The equations have been used by the authors group in their studies of various power plants and plant cycles and are considered to be satisfactory. Further development of additional coverage will be made as other data become available.

HIGH TEMPERATURE TURBINE MACHINERY FOR MARINE PROPULSION

ACKNOWLEDGEMENT

This is an abridged version of the Thomas Lowe Gray lecture before the Institution of Mechanical Engineers on 15 January 1954. The author, Mr. T. W. F. Brown is the Research Director of the Parsons and Marine Engineering Turbine Research and Development Association (Pametrada). This article appeared in the January 22 and 29, and February 5, 1954 issues of "The Engineer."

I—STEAM TURBINES

CONSIDERATIONS CONTROLLING UPPER LIMIT OF STEAM TEMPERATURE

Materials have been tested in the laboratory scale up to 1800 deg. F., but it is felt that even in this survey a top metal temperature of 1700 deg. F. in the superheater tubes is the best that can be expected in the present state of the art. With this limit a top temperature of steam leaving the superheater of 1500 deg. F. has been chosen. When it is clear that a good design can be achieved with a heat drop in the first stage nozzles corresponding to a tempeature drop of 100 deg. F., the highest temperature of steam impinging on the blading and surface of the rotor is 1400 deg. F. The mean temperature in the rotor body is lower than this, since the isothermals in the rotor show heat flowing from the hottest part of the rotor to the cooler parts farther down the expansion, and the temperature at the rotor bore below the first-stage disc will not exceed 1350 deg. F. Designs could be suggested which could use the stresses available at the appropriate temperatures in the materials to produce a practicable turbine.

In an earlier section designs of turbines are shown where the glands and bearings are remote from the hottest zone of the turbine. It is also clear that the double-casing design of turbine would be essential. The main outer casing would then only have to deal with temperatures of the order of 1100 deg. F., this being the temperature of steam exhausting from the inner casing. Such considerations fix a limit for steam temperatures up to 1500 deg. F. at turbine inlet. The effect of up to two stages of reheat at this temperature will also be examined.

STEAM TURBINE HEAT RATES AND EFFICIENCIES AT HIGH TEMPERATURE

Land Turbines. — Information derived from the firms which have helped the author by supplying particulars, and from published sources, is given in Table I. "Gross" refers to the heat rate per kilowatt-hour of turbines only and "net" to the overall figure including boiler efficiency and auxiliary requirements. Most turbine manufacturers give the gross figure, and the net is then derived from the boiler efficiency and the appropriate auxiliary system.

Fig. 1 shows the estimated variation of turbine heat rate with steam temperature over the range 850-1500 deg. F. for a unit of about 60MW. Curves are shown for cycles without reheat, and with one and two stages of reheat. Six stages of feed heating are assumed, and pressure drops in the reheaters of 5 per cent, which is a practicable value for liquid-metal-coupled reheaters.

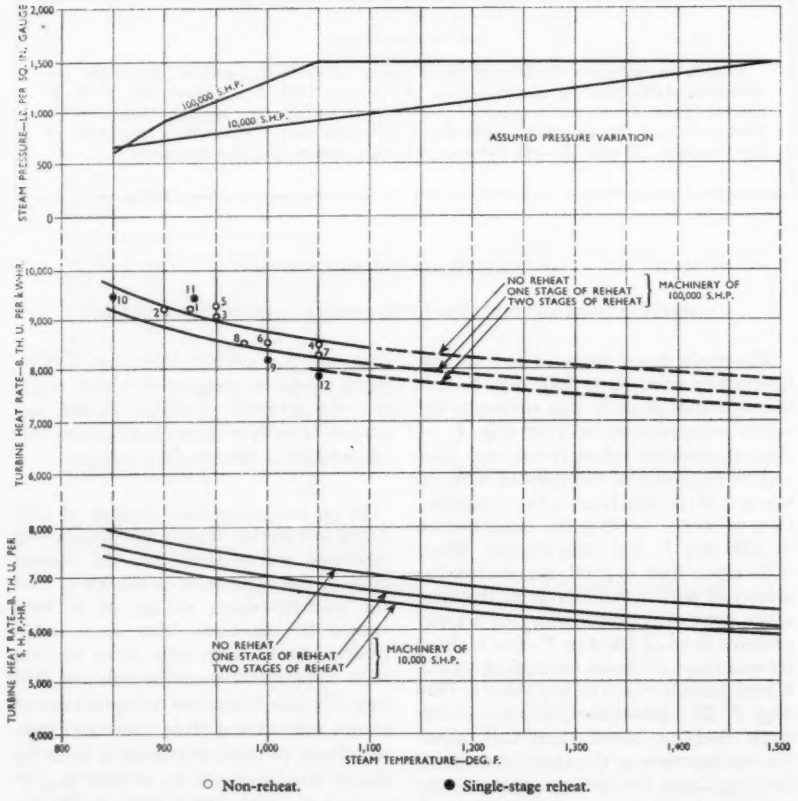


Fig. 1—Variation of Heat Rate with Steam Temperature for Machinery of about 100,000 and 10,000 S. H. P.

TABLE I—SUMMARY OF TURBINE HEAT RATES FOR POWER STATION MACHINERY

Station	Point on graph (Fig. 1)	Turbine manufacturer	Steam conditions			Stages of feed heating	Feed temperature, deg. F.	Capacity, megawatts	Heat rate at most economic rating, B.T.U. per kW-hr	Source of information
			Lb. per sq in gauge	Temperature, deg. F.	Inches, of mercury					
			Non-reheat plants							
—	1	C. A. Parsons and Co. ..	900	925	—	—	—	60	about 9200	Builders
—	2	English Electric Co. ...	900	900	28.7	5	385	60	9224	Builders
—	3	English Electric Co. ...	1250	950	28.86	5	460	60	9042	Builders
—	4	English Electric Co. ...	1500	1050	28.9	6	410	100	8463	Builders
Willesden	5	(1) Metropolitan-Vickers Electrical Co. .. (2) English Electric Co..	1300	950	28.7	6	360	30	(1) 9287 (2) 9302 mean 9295	Clinch (1949)
Essex No. 1	6	General Electric Co. ..	1250	1000	28.5	8	—	100	8500	Renton and Neal (1950)
Sewaren Nos. 2.. and 3	7	General Electric Co. ..	1500	1050	28.5	8	453	100	8250	Fairchild (1950)
Dampf Waftwerk Weisweiler, Aachen	8	Brown Boveri and Co. .	1550	977	28.25	6	415	150	8500	*Brown Boveri Review* (1953)
			Single-stage reheat plants							
—	9	C. A. Parsons and Co. ..	1500	1000/1000	—	—	—	100	About 8200	Builders
Dunston "B II" .	10	C. A. Parsons and Co. ..	600	850/850	28.75	4	346	50	9460	Howell and Jackson (1953)
Brimsdown "A".	11	Metropolitan-Vickers Electrical Company .	1900	930/810	28.7	5	355	53	9407	Clinch (1949)
Philip Sporn	12	General Electric Co. ...	2000	1050/1000	28.5	8	441	141	Net 9270 Gross 7820	Sporn (1948)
			Two-stage reheat plant							
Philo	13	General Electric Co. ...	4500	1100/1050/1000	29	7	515	120	Net 8200	*Electrical World* (1953)

The assumed variation of steam pressure with temperature is shown on the curve. The numbered points inserted in Fig. 1 are those taken from Table I. Where the points are lower than the curves they are all explainable by some such factor as that the size of the unit is larger than 60MW (the basis of the calculations), or that more stages of feed heating than six are being employed, or that a change has taken place in inlet pressure or vacuum (the basis being 28½ in. of mercury). As the curves are established by these figures up to 1100 deg. F., and as there is little doubt about the thermodynamic properties of steam, it is hoped that the curves are sufficiently useful to show trends up to 1500 deg. F.

Table II gives the derivation of overall thermal efficiencies from those calculations made on the basis of turbines only.

TABLE II—ESTIMATED EFFICIENCY OF POWER STATION MACHINERY OF 60MW

Steam conditions		Thermal efficiency (gross, turbines only), per cent	Auxiliary power, per cent	Boiler efficiency, per cent	Overall efficiency (net) per cent
Lb per sq in gauge	Temperature, deg. F.				
600	850 (noreheat)	35.2	4.1	88	29.7
600	850 (plus 1) reheat	37.1	4.1	88	31.3
1500	1200 (noreheat)	41.6	4.6	88	35.0
1500	1200 (plus 1 reheat)	43.2	4.6	88	36.4
1500	1200 (plus 2 reheats)	44.7	4.6	88	37.7
1500	1500 (noreheat)	44.0	4.0	88	37.3
1500	1500 (plus 1 reheat)	45.8	4.0	88	38.7
1500	1500 (plus 2 reheats)	47.3	4.0	88	40.0

The auxiliary powers for the straight cycle in Table II have been extrapolated from curves given by Finniecombe (1946) and assumed to be the same for the reheat cycles as for the straight cycles. This checks very well with the net and gross heat rates given in Table I for the Philip Sporn station with conditions of 2000 lb. per square inch gage, 1050/1000 deg. F. and 28½ in. of mercury.

Marine Steam Turbine Units.—Although powers developed by marine steam turbine machinery per shaft are tending to increase, it is still true that the majority of steam turbine sets have an average value of something under 10,000 s.h.p. Calculations similar to those already outlined have been made for turbine machinery of this power. The basic turbine efficiencies used were 0.78 for high-pressure and 0.88 for low-pressure turbines, with suitable adjustments for such factors as pressure and wetness in the low-pressure turbine. A vacuum of 28½ in. of mercury has been assumed throughout. The turbine heat rates are given in Fig. 1 together with the pressures assumed to be appropriate to the chosen steam temperature. Until turbine construction changes basically, high pressures are not appropriate to small units, since parasitic losses rise in proportion to increase in pressure. However, with a turbine of constant s.h.p., some increase in pressure can be accepted with increase in temperature to maintain constant volumetric flow and hence efficiency.

A summary of the results for the marine set of 10,000 s.h.p. is given in Table III. The auxiliary factor mentioned in the table is the ratio of (effi-

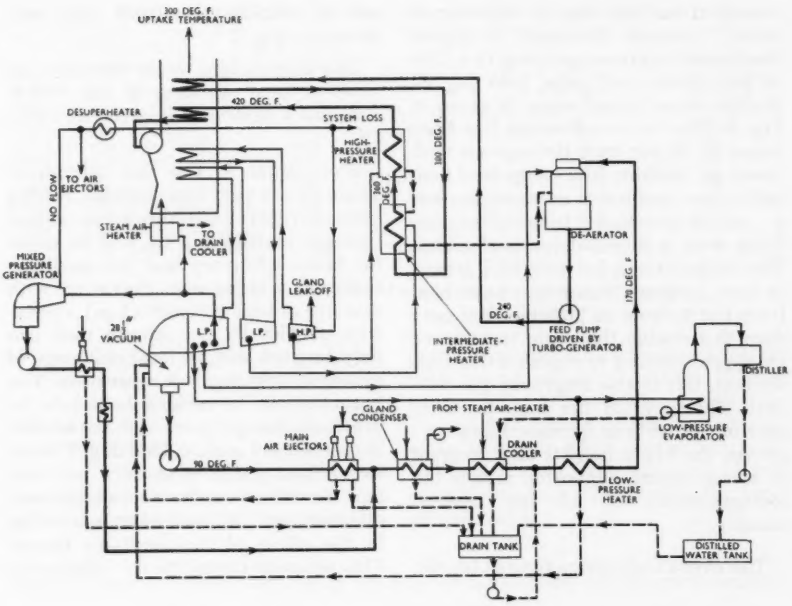


Fig. 2—Feed Diagram for Double Reheat Installation

TABLE III—SUMMARY OF THE RESULTS OF CALCULATIONS FOR A MARINE STEAM TURBINE UNIT OF 10,000 S.H.P.

Conditions			Reheat points	Heat rate		Auxiliary factor (propulsion only)	Thermal efficiency		Fuel rate (propulsion only), lb. per s.h.p./hr.
Inlet pressure lb. per sq. in. gauge	Inlet temperature deg. F.	Vacuum inches of mercury		B.Th.U. per s.h.p./hr.	B.Th.U. per equivalent kW-hr.		Turbines only, per cent	Overall, per cent	
650	850	28½	None	7,941	10,650	1.060	32.1	26.6	0.516
650	850	28½	1	7,596	10,180	1.067	33.5	27.6	0.498
650	850	28½	2	7,423	9,950	1.070	34.3	28.2	0.488
1,100	1,200	28½	None	6,855	9,190	1.069	37.1	30.6	0.450
1,100	1,200	28½	1	6,574	8,820	1.070	38.7	31.8	0.432
1,100	1,200	28½	2	6,383	8,560	1.079	39.9	32.5	0.423
1,500	1,500	28½	None	6,410	8,590	1.077	39.7	32.4	0.424
1,500	1,500	28½	1	6,060	8,120	1.083	42.0	34.1	0.403
1,500	1,500	28½	2	5,926	7,940	1.082	42.7	34.9	0.394

Reheat in all instances to initial temperature.

The column for equivalent heat rate per kilowatt-hour has been added to enable the figures to be compared with those applicable to turbo-alternators already given.

ciency of turbine only × efficiency of boiler) / (overall efficiency). A typical feed cycle diagram, applying to a 1500 lb. per square inch gage, 1500 deg. F., double reheat installation, is given in Fig. 2. The boiler efficiency has been taken as 88 per cent throughout with steam air heaters, four-stage feed heat with upper and lower economizers and a mixed-pressure turbo-alternator fitted with a direct-drive feed pump. The evaporator is fed with bled steam. In fact, as much steam has been bled from the turbine as possible. Not only does this enable the cycle to improve by approximating to regenerative feed heating, but it also improves the turbine efficiency. In the high-pressure part of the turbine increased flow improves the blade heights and removal of steam during expansion makes the low-pressure end of the turbine smaller.

The overall efficiency figures for the sets of 100,000 and 10,000 s.h.p. are shown in Fig. 3.

The calculations were repeated for super-critical working at the 60MW size and a summary is given in Table IV.

The values in the last column of Table IV are very approximate, having been derived from the gross values through multiplying by 0.83 to cover for boiler efficiency and the auxiliary factor. It will be seen that even with this size of unit (100,000 s.h.p.) a pressure of 4500 lb. per square inch can only be used with at least one stage of reheat at 1200 deg. F. temperature. The improvement in turbine heat rate by pressure change from 1500 lb. to 4500 lb. per square inch at 1500 deg. F. with two reheat points is about 6 per cent and the effect on the overall thermal efficiency will be somewhat less owing to the effect of the auxiliary factor. This pressure in marine use could only

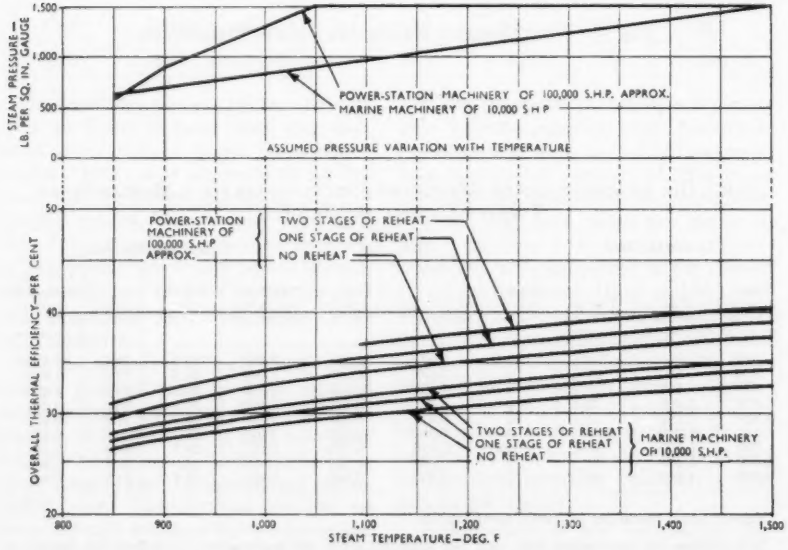


Fig. 3—Variation of Overall Thermal Efficiency with Temperature for Units of About 10,000 and 100,000 S. H. P.

TABLE IV—SUMMARY OF CALCULATIONS OF HEAT RATES FOR A 60MW SIZE OF UNIT

Steam conditions		Heat rate (turbines only)	Condition at exhaust	Thermal efficiency (gross),	Approximate overall efficiency (thermal)
Lb. per sq. in. gauge	Temperature, deg. F.	B.T.U. per kW-hr.		per cent	per cent
4500	850 (no reheat)	8860	27.3 per cent wet	38.6	32
4500	850 (plus 1 reheat)	8300	14.7 " "	41.2	34
4500	850 (plus 2 reheats)	7970	7.3 " "	43.0	35
4500	1200 (no reheat)	7830	15.6 " "	43.7	36
4500	1200 (plus 1 reheat)	7510	7.3 " "	45.5	38
4500	1200 (plus 2 reheats)	7290	0.3 " "	47.0	39
4500	1500 (no reheat)	7400	9.8 " "	46.2	38
4500	1500 (plus 1 reheat)	7100	1.0 " "	48.0	40
4500	1500 (plus 2 reheats)	6840	120 deg. F. superheat	50.0	40

Reheat in all instances to initial temperature; vacuum of 28½ in. of mercury.

be considered for the one or two high-powered ships which may be built in the future. Super-critical pressure calculations have not been made for a set of 10,000 s.h.p., as they are not realistic with present constructional knowledge. From these considerations it would appear that the improvement possible in marine turbines of 10,000 s.h.p. using pressure of 1500 lb. per square inch, temperature of 1500 deg. F., and two reheat points over simple expansion from 650 lb. per square inch, 850 deg. F., is of the order of 24 per cent in the fuel consumption for propulsion only.

SOME PRACTICAL CONSIDERATIONS IN THE MARINE USE OF HIGH-TEMPERATURE STEAM

Boilers.—With the related increase in pressure and temperature, boiler drums would tend to be reduced or eliminated. The suggested type of boiler would have pressure combustion and high gas speeds. The Velox boiler has, in fact, such characteristics. The last expansion of the exhaust gases through a turbine would enable reasonable boiler efficiencies to be obtained without unduly low temperatures at the air heaters which, particularly at part load, have been found to lead to fouling and corrosion. A section of the economizer could also be eliminated. At a pressure ratio of 3.5 the temperature drop through the gas turbine driving the air charging blower would be about 230 deg. F., which means that the gas leaving the boiler could have a temperature of, say, 500 deg. F. with a temperature at funnel base of 270 deg. F. The type of gas turbine would be the simplest possible, a common rotor carrying the centrifugal compressor supplying air to the registers and the centripetal turbine. No high temperature problems would be involved. Great experience has already accumulated in operating gas turbine combustion chambers at the pressure of 3.5 atm. with residual fuel with a heat release of the order of 2.5×10^6 B.T.U. per cubic foot per atm. per hour leading to a small furnace. This heat release can be associated with high boiler efficiencies when combined with a gas turbine.

Superheaters.—In regard to the highest temperatures in the steam cycle, the superheater tubes are the first part in the installation to be really hot apart from refractories in the furnace. Possible materials have already been referred to. It is clear, however, that vanadium attack on high-temperature alloys is likely to show up in the same way as has already appeared in the running of gas

turbines on residual oils with an inlet temperature of 1250 deg. F. This effect is discussed below in the section on residual fuel burning.

The Research Committee on High-Temperature Steam Generation of the American Society of Mechanical Engineers is studying the behavior of superheater tubing materials in combustion atmospheres at 1350 deg. F. at the Battelle Memorial Institute. The Naval Boiler and Turbine Laboratory at Philadelphia has also a similar program to examine first the effect of temperature alone, then high sulphur content in the fuel followed by the addition of vanadium and other ash constituents. Purdue University is examining heat transfer rates as affected by the formation of internal and external films.

Two progress reports—one by Ely and Eberle (1952) (giving the results of over 4000 hours of service, with 500 hours at 1250 deg. F. or higher and 1600 hours at 1200 deg. F. or higher), and the other by Slunder, Hall and Jackson (1953)—have already appeared. It will be seen that if research work in the United States can speed progress the use of the temperatures examined in the paper is not too far away.

Reheating.—Reheating can be performed in three ways:—

(1) Steam reheat, as used in the "Venroe" (Robinson and Worthen, 1946). With an initial temperature of about 1000 deg. F. this form of reheating would be useless, since the steam reheaters can only heat up the turbine steam to about the saturation temperature corresponding to the initial boiler pressure if this forms the supply of heating steam. It is clear, however, that a self-contained heating circuit can be built into the boiler with a higher pressure than the steam supply to the turbines. Even so, however, the saturated temperature at critical pressure is only 705.4 deg. F.

(2) Gas reheat where steam is led from the turbine through a section of the boiler and reintroduced to the turbine. This is suitable for one stage of reheat in marine use in the present state of the art, but, in general, space requirements in a ship would not permit the accommodation of four sets of such high-temperature steam pipes in addition to the main steam pipe if two-stage reheating were required.

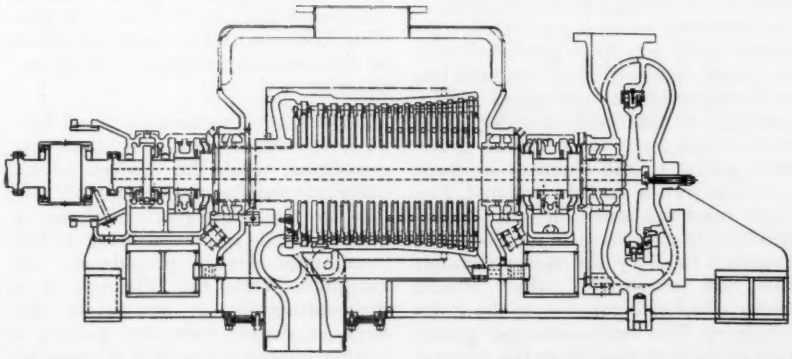
(3) Recent developments in the use of liquid metals (such as sodium and sodium-potassium alloy) as heat transfer fluids in the development of nuclear power plants have opened up the possibility of their use as reheating media in steam turbine plants. The liquid metal would transfer heat from a heater section in the boiler to a heat exchanger adjacent to the turbine. This would eliminate the large hot steam pipes between turbine and boiler and replace them by the much smaller pipes carrying liquid metal. Thus two stages of reheat would become feasible in marine use and pressure drops on the steam side could be limited to, say, 5 per cent of the pressure head with a compact design of reheater.

Circulation of the liquid metal requires little power. Even at inlet conditions of 600 lb. per square inch and 950 deg. F. with four stages of feed heating, the gain due to liquid metal reheating would be 8 per cent, a figure which might well justify the increased cost and complexity of the liquid metal circuit. Mechanically, reheat would reduce moisture in the low-pressure stages and would permit higher blade speeds, without erosion being an important factor. Continuous reheating in the turbine, using liquid metal in the

fixed blades or diaphragms of the turbine, is unlikely to be used, since too little area is available in such parts for heat transmission to enable appreciable gains to be achieved. Special precautions would, of course, be necessary to prevent the liquid metal from coming into contact with air or water, but successful operation of pilot plants in Britain and the United States proves that the difficulties can be overcome. In any event high superheated steam at high pressure is itself a dangerous fluid.

Design data and experience are given in Brooks and Rosenblatt (1952), and in the papers given by Hayden (1953), Perkins (1953), and Boadle (1953) at a conference at the Atomic Energy Research Establishment, Abingdon, in May, 1953.

Turbines.—At the higher temperatures explored in this lecture, astern turbines would not be used since the special piping, valves, and astern turbine casings would cost much more than alternative solutions, apart from the question of sudden heating through the range of temperature involved. The elimination of astern turbines would also enable more stages to be fitted and with the elimination of windage in this element the highest economic vacuum would be somewhat increased. Boiler operation during maneuvering would also be too complicated if attemperation of the steam were attempted. If one may hazard a guess as to the form of high-pressure turbine, it will have a double casing with end assembly of the inner portion held together by longitudinal bolts in the exhaust space. Owing to their length such bolts would have considerable resilience, and the horizontal joint which is a bad enemy of symmetry—however reduced—would be eliminated. Pipes conveying steam in and out of the inner casing would be arranged flexibly as shown in most of the earlier examples of high-temperature turbines, and the general assembly of the outer casing would be as in Fig. 4. The hot portion of the inner casing with the diaphragm separation between inlet steam and reintroduction of the reheated steam would be in the center in a comparatively simple casing. Succeeding stages would be built up of the split diaphragms already in place in the rotor, the whole assembly being held by end clamps at



Steam Conditions, 600 lb. per square inch gauge, 950 deg. F., 28½-in. of Mercury; speed, 3980 r. p. m.

Fig. 4—High-pressure Turbine for Pametrada Installation of 12,500 S.H.P.

the two exhausts into the outer casing. Supervisory gear to measure and record relative expansion between rotor and casing, eccentricity of casings, etc., during heating up and cooling down, would be required.

As the low-pressure inlet would also be a reheat point when two stages of reheating were designed, the hot inlet would again be in the center with double-flow exhaust to the end. Two-casing construction would be inevitable. Even at a pressure of 1500 lb. per square inch, inlet temperature of 1500 deg. F., and two stages of reheat to 1500 deg. F., the exhaust temperature at a vacuum of 28½ in. of mercury is only 367 deg. F. For sets larger than 10,000 s.h.p. the value of turbine efficiency would be greater and, consequently, the temperature at exhaust would be less.

Condenser.—In general the condenser would become smaller with the improved steam rates resulting from higher temperatures at any given power. It has already been stated that for the most severe conditions examined the steam exhausting from the low-pressure turbine at a vacuum of 28½ in. of mercury is superheated. A cooler incorporated as part of the condenser shell may be suggested. It will be found, however, that this heat has to be wasted, since the use of it as a precooler to heat the feed water introduces a net cycle loss of about ¾ per cent owing to the increase in back pressure on the turbine exhaust. For some cases examined, in order to get practicable sizes, ½ in. in mercury was required to carry the steam through this heat exchanger, which would mean a loss of 2 per cent in the cycle efficiency. This heat exchanger giving heat to the feed water from the exhaust steam before condensation only improves the cycle by 1¼ per cent. This is clearly ruled out by the loss caused by the increase in back pressure in the low-pressure turbine.

It would be possible to use condensate sprays at the turbine exhaust to reduce the superheat in the steam before it impinged on the tubes, which might reduce the condenser surface. The highest temperature in exhaust in the extreme case examined is 367 deg. F. and can be dealt with in existing condenser designs. No modifications to the feed cycle diagram shown in Fig. 2 are therefore required.

It may be remarked that for a 10,000 h.p. unit at 1500 deg. F. with two stages of reheat a pressure of the order of 15,000 lb. per square inch would be required, to have the steam just wet at a vacuum of 28½ in. of mercury after completing expansion through the turbine. The corresponding figure for the 100,000 s.h.p. turbine would be about 10,000 lb. per square inch, owing to the improved turbine efficiency appropriate to the size, which involves less reheat on the expansion line. For the Philo station the corresponding figure is 4500 lb. per square inch for a horsepower of about 158,000 at the temperatures already given. These figures indicate the order of magnitude of pressure required to get the exhaust steam into the wet field, but it is possible to deal with the superheat steam in the condenser without it being undue size.

Gearing. — The unidirectional turbines without astern elements, already postulated, would be coupled to the main line shafting driving the propellors by reduction gearing. Three or more methods of maneuvering (other than turbo-electric propulsion) are available. While the efficiency of a turbo-alternator is practically the same as double-reduction gearing a further energy conversion is required in the motor, which reduces the efficiency to about 92 per cent as against 98 per cent for the gearing.

(1) *Controllable Pitch Propeller.*—This solution would best suit two-speed ships, e.g. tugs, trawlers, and minesweepers with the conditions of towing and running free, but such ships are not likely to have high-temperature steam turbine machinery. For ordinary merchant ships the best propeller is one having fixed pitch; and the complexity of having moving gear in the shafting and propeller boss is best avoided, particularly as the larger boss required with a controllable pitch propeller adversely affects the propeller efficiency.

(2) *Torque Converters.* — With an ahead fluid flywheel efficiencies up to 98.3 per cent have been achieved. The torque converter for astern running is also comparatively simple and efficiencies high enough to give good stopping and backing power have been developed.

(3) *Airflex Couplings and Oil-operated Clutch Gears.*—These have been proved in smaller sets but have an inherent limitation in regard to power which can be transmitted even when more than one is used simultaneously, particularly at high speed. An idle gear pinion may also be required for reversing, which may give trouble in ahead running without load.

(4) *Epicyclic Reduction and Reverse Gear.*—An example of this design of gear is shown in Fig. 5 for a power of about 10,000 s.h.p. with a reduction ratio of 56 ahead and 40 astern.

The maneuvering is carried out by means of multiple-disc brakes hydraulically applied and cooled by oil. This enables the large inertia load in the shafting, propeller and gears to be taken up without overheating. The size and weight is small; accurate teeth can be produced on comparatively small machines; and the general arrangement of the gear suits a tandem arrangement of turbines driving into a single pinion. A single pinion transmitting the whole power of the set means a very large box in the usual arrangement of double-reduction gearing and one of the reversing ar-

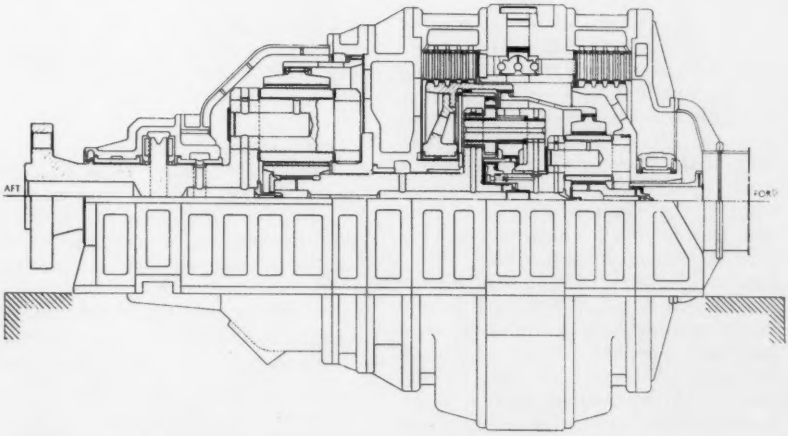


Fig. 5—Epicyclic Marine Reduction and Maneuvering Gear for a Power of About 10,000 S.H.P.

rangements mentioned earlier would also have to be incorporated. In a normal design of gearbox, turbine power is applied on two or three high-speed pinions at the first reduction stage and there are many arrangements to spread this power over a larger number of secondary pinions to reduce the size of the main wheel at any required reduction ratio.

Auxiliaries.—These would be largely motor driven with steam turbine driven standby sets. The turbo-generators should be of the mixed-pressure type taking steam from the main turbines at a comparatively low pressure. In this way even in a set of small output the blade heights would be such that efficiency was high. A governor would be fitted to admit attemperated boiler steam through separate nozzles if the steam flow from the main turbine were too little during shut-down, maneuvering, or low-power running. The turbo-generator reduction gearing would drive the feed pump from a pinion and thus the main auxiliary load would be provided at an economical steam rate. Gas turbine generator units are now becoming available and the exhaust would be led into the boiler furnaces, thus eliminating the somewhat bulky heat exchanger sometimes associated with them.

In the previous feed calculations for a 10,000 s.h.p. marine set an equivalent total of 260-350kW was generated for the propulsion auxiliaries and feed pump and is allowed for in the calculations of propulsion-only fuel rate.

Engine-room arrangement would involve having boilers on a shelf over the gearing at the aft end of the engine-room to keep steam piping to a minimum consistent with flexibility. This arrangement would give good hairpin bends in the vertical legs and good drainage arrangements.

II—GAS TURBINES

THE GAS TURBINE FOR MARINE USE

Many summaries of the position of gas turbines in Britain and overseas have been made from time to time, and no attempt will be made to produce another. Quite the best is the series given as "Gas Turbine Progress Report, 1952." Three of the twelve papers apply specifically to marine aspects: marine, merchant vessels and naval vessels. One of the points on which information is lacking has been actual figures obtained on test and reports on running experience gained. In uncooled gas turbines of the multi-stage long-life type, inlet temperatures do not greatly exceed 1250 deg. F. (677 deg. C.). With some air cooling of the turbine rotor at inlet, or cooling pads fitted adjacent to the turbine disc (cooling by radiation), temperatures increase to 1450 deg. F. (788 deg. C.) as a maximum for long-life operation. In this lecture only long-life gas turbines required for ship propulsion will be considered.

The Pametrada marine gas turbine developing 3500 s.h.p., which was designed in 1946 and which has been operating since December, 1948, is quite the most useful tool which could have been devised to examine the problems of distortion, controls, component efficiencies, the combustion of residual fuels and the related matters of "build-up" and corrosion. New mechanical parts such as glands, pipe joints, etc., have also been proved. Details of the cycle and construction have been given in a previous paper (Brown, 1949).

TABLE V—TEST RESULTS UNDER VARYING CONDITIONS FOR PAMETRADA 3500 S.H.P. MARINE GAS TURBINE

Run	A	B	C	D	E	F	G

TABLE V—TEST RESULTS UNDER VARYING CONDITIONS FOR PAMETRADA 3500 S.H.P. MARINE GAS TURBINE

Run	A	B	C	D	E	F	G
Atmospheric conditions:							
Pressure, pounds per square inch absolute	14.92	14.7	14.7	14.7	14.69	14.53	14.74
Temperature, degrees Fahrenheit absolute	486	517.4	518	518.7	533.5	512.3	505.8
Mass flow to low-pressure compressor (corrected to 80 deg. Fah., 14.7 lb per square inch), absolute), pounds per second	47.7	47.0	46.45	46.4	47.8	47.1	42.9
Low-pressure compressor:							
Inlet pressure, pounds per square inch absolute	14.73	14.53	14.53	14.53	14.51	14.36	14.58
Outlet pressure, pounds per square inch absolute	30.62	29.71	29.81	29.72	29.08	30.02	33.94
Outlet temperature, degrees Fahrenheit absolute	627.5	668.5	666.8	666.0	684.1	662.3	668.6
Efficiency, per cent	79.7	78.3	79.4	79.6	77.6	80.5	85.0
Mass flow to high-pressure compressor (corrected), pounds per second	48.8	47.6	47.1	47.1	49.45	46.8	38.6
High-pressure compressor:							
Inlet pressure, pounds per square inch absolute	29.8	29.18	29.09	28.98	28.20	29.26	33.33
Inlet temperature, degrees Fahrenheit absolute	532	540.9	539.3	538.5	543.8	534.9	542.5
Outlet pressure, pounds per square inch absolute	81.42	76.7	75.45	74.7	74.69	78.73	86.24
Outlet temperature, degrees Fahrenheit absolute	725.5	733.7	728.7	725.8	736.9	731	741.8
Efficiency, per cent	91.3	89.5	88.6	89.2	90.0	89.1	85.0
High-pressure turbine plus compressors: speed, revolutions per minute	4495	4428	4395	4380	4530	4390	4260
High-pressure turbine:							
Mass flow, pounds per second	49.1	46.43	46.04	45.94	46.62	46.07	42.92
Inlet pressure, pounds per square inch absolute	78.67	74.2	72.93	72.45	72.12	76.23	84.44
Inlet temperature, degrees Fahrenheit absolute	1599	1638	1618	1615	1568	1660	1654
Outlet pressure, pounds per square inch absolute	28.13	26.81	26.41	26.34	24.28	26.54	25.22
Outlet temperature, degrees Fahrenheit absolute	1261	1302	1286	1285	1220	1318	1294
Efficiency, per cent	84.9	86.3	85.9	85.4	84.75	83.1	77.25
Low-pressure turbine:							
Inlet pressure, pounds per square inch absolute	27.84	26.20	25.81	25.78	23.78	—	—
Inlet temperature, degrees Fahrenheit absolute	1620.5	1639	1592	1617	1213	—	—
Outlet pressure, pounds per square inch absolute	15.17	14.95	14.94	14.93	14.90	—	—
Outlet temperature, degrees Fahrenheit absolute	1413	1446	1407	1429	1082	—	—
Efficiency, per cent	84.6	83.7	82.0	83.2	82.0	—	—
Shaft horsepower	3588	3171	2972	2980	1937	—	—
Fuel consumption, pounds per hour	1755	1680	1596	1599	1322	—	—
Specific fuel consumption, pounds per shaft horsepower-per hour	0.488	0.530	0.538	0.536	0.684	—	—
Thermal efficiency, per cent	28.95	26.7	26.3	26.4	20.7	—	—
Heat exchanger thermal ratio	80	80	83.6	80	77.3	74.3	80.1
Reduction in swallowing capacity, per cent	—	—	—	—	—	3.57	20.40

The set has now been coupled through hydraulic couplings and reduction gear to the large brake (60,000 b.h.p. at 160 r.p.m.). At the designed main shaft speed at full load of 85 r.p.m., a power of 3500 s.h.p. represents about one-quarter load on the brake at this speed owing to the operation of the "propeller law." Typical test results under different conditions are given in Table V.

The values quoted under turbine efficiencies are calculated from pressures, flows and work done.

The runs were carried out under the conditions shown in Table VI.

TABLE VI—CONDITIONS OF RUNS

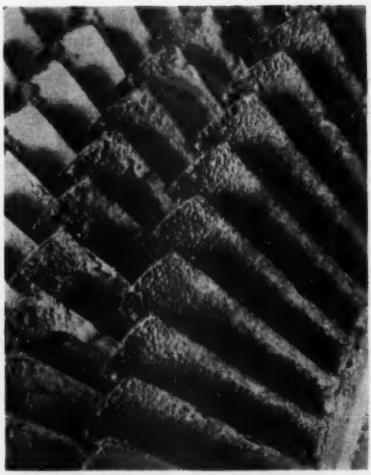
A	B	C	D	E	F	G
Full load .... Gas oil fuel ..	Full load .... Gas oil fuel..	90 per cent load ..... Gas oil fuel..	90 per cent load ..... Gas oil fuel..	60 per cent load ..... Gas oil fuel..	Equivalent full load .. Residual fuel "Mothball" with magnesium acetate as additive	Equivalent full load .. Residual fuel "Mothball" with magnesium acetate as additive
Equal temperature at inlet to high-pressure and low - pressure turbines	Equal temperatures in high-pressure and low - pressure turbines	Equal temperatures in high-pressure and low - pressure turbines	Higher temperatures in high-pressure than low - pressure turbine	This is near maximum power obtainable without use of reheat combustion chambers	Low - pressure line out of operation. Beginning of run	Same run as F, nearly 84 hours later prior to high - pressure compressor stall which ended the run

Test results in columns A-E inclusive give the readings from normal runs to examine the efficiency of the compressors, intercoolers, turbines, and heat exchanger. It will be seen that the low-pressure compressor has an efficiency of about 79 per cent. This was due to mismatching of the components, the original compressor being too large. By cutting down the rotor blade heights, filling in the annuli between fixed blading with rings and fitting spacers between blades, the capacity was corrected, but the efficiency suffered. If the low-pressure compressor were redesigned an efficiency of 87 per cent should be possible. This would produce an increase of about 11 per cent in thermal efficiency and 13.5 per cent in specific power, and the overall thermal efficiency would become 31 per cent. Even now the figure for specific fuel consumption in column A is the lowest known to the author. As corrected it would certainly be better than a steam turbine plant of this output with an inlet temperature of 1000 deg. F. It will be apparent that this experience of operation at 1250 deg. F. is available for improvements in steam turbines to operate at similar temperatures, particularly if two-stage reheat is employed when similar pressure and temperatures will occur at the lower reheat position.

Residual Fuel Burning.—Investigations into the problem of residual fuel burning began on a laboratory scale with attempts to remove ash-bearing constituents in the fuel by a two-stage centrifuging process, by use of butane, propane, phenol and aniline as solvents, by the action of concentrated sulphuric acid, and by other means. This series of attacks on the problem was abandoned as none of the solvent methods showed any promise of removing the ash-bearing constituents from residual oils except at a prohibitive expense, and as the results of the centrifuging trials were also negative.

Studies on inhibition of the corrosion caused by vanadium and sodium-bearing fuel ashes were therefore started. Samples of all commonly used high-temperature alloys were obtained. It was shown that, of all the substances used for inhibition, magnesium oxide, zinc oxide and vermiculite (a complex mica-like silicate) were capable of reducing the attack to satisfactory proportions, while kieselguhr and alumina were effective but not so good. A serious warning arose, however, from these tests in that, with the exception of magnesium compounds, all the additives were not only capable of failing to reduce the corrosion, but could also bring about accelerated attack when present in certain critical proportions. These laboratory investigations have been reported by two of the author's colleagues (Frederick and Eden, 1954). Rig tests were then carried out with a small combustion chamber fitted to burn fuel oil, a chemical pump adding the inhibitors to the fuel before spraying, and into the spray. The resulting gas was discharged from the combustion chamber on to target specimens fitted with thermo-couples. The correlations between laboratory and rig tests were good.

This experience enabled running tests to begin on the 3500 s.h.p. gas turbine using Admiralty reference fuel "Mothball." This was the worst residual fuel found in laboratory tests. The ash content is 0.05 per cent, of which 60 per cent can be reduced to vanadium pentoxide by analysis. Columns F and G represent the beginning and end of a test at full output in the high-pressure turbine which terminated after eighty-four hours when the compressor stalled owing to build-up of deposit in the high-pressure turbine. These tests were run with the low-pressure line cut out and a nozzle installed in the high-pressure turbine discharge corresponding to the back pressure developed by the low-pressure turbine. This simplified the running and reduced the amount of corrosion damage which might occur. That is why no figures for the low-



(a) Rotor blading

(b) Casing blading

Fig. 6—Condition of Gas Turbine Rotor and Casing Blading after 84-hour Run on Heavy Fuel Oil

pressure turbine appear in columns F and G of Table V.

Fig. 6 shows the condition of rotor and casing blading when opened up after the run of eighty-four hours.

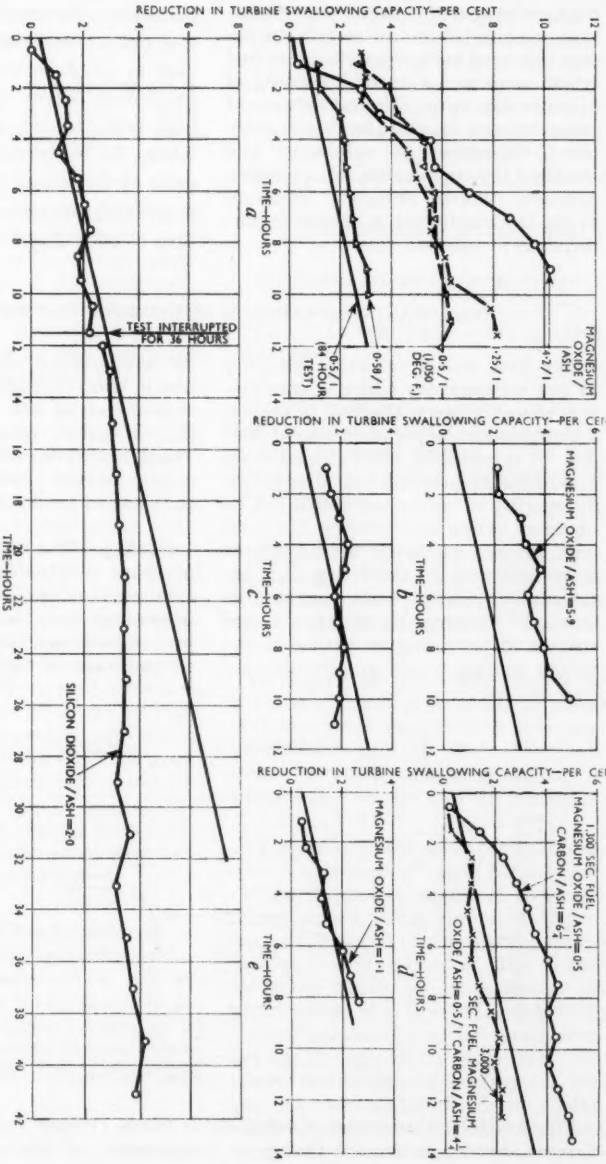
The swallowing capacity of the turbine was measured by using the inlet flow parameter $G\sqrt{T}/P$ as a measure of change of area, where G = mass flow, T=absolute temperature, and P=absolute pressure.

Owing to reduction in flow area through the turbine, the pressure ratio of the cycle is increased and the mass flow decreased. This causes the operating line on the compressors to move towards the surge line. Results of other runs with different additives are shown in Fig. 7, the full line in each instance being the eighty-four hour run which was used as a means of comparison. By comparing the slopes of the curves it was possible to use shorter runs and decide early in the test whether the rate of build-up was better or worse than before. It will be seen from the lowest curve shown on this diagram that an additive has been found for which the build-up is quite bearable over long periods. The run on kerosene with an additive introduced was arranged in order to provide a sulphur-free fuel to determine whether sulphur affected fouling. It was found that it did. With all the additives mentioned, the turbine, when cold, was effectively cleaned between runs by washing with water.

For every ton of Mothball fuel burnt the ash content is 1.1 lb. If to this is added 2 lb. or more of inhibitor, the amount of material to be handled by the turbine is trebled. If it sticks, the build-up is increased and, although corrosion attack may be stayed, the turbine is still not able to utilize residual oil. It is therefore necessary to produce solids which, while inhibiting corrosion, pass through the turbine without sticking or causing build-up in the subsequent components. Some experience with ethyl silicate as an additive appears to show that this requirement has been met. At lower temperatures sticking did not occur with other additives and the heat exchanger remained clean throughout.

Depression of the combustion to produce carbon was tried, but was unsuccessful. In vortex combustion chambers it has been possible to control combustion so that each droplet of oil continues to burn until only the minimum amount of carbon, with the ash content still undispersed, remains. With the straight-through combustion chamber it could not be achieved, and, in any event, this method would appear to be too critical for practical use. In such combustion chambers there are considerable losses caused by the presence of unburnt products in the gas as long as some carbon from the fuel remains unburnt. It may appear that too much is made of the burning of residual fuels, but it—as well as the use of residual fuels in gas turbines—is the clue to the operation of high-temperature steam superheaters in boilers.

Cleaning of Compressors.—Throughout the extensive series of trials the low-pressure compressor remained clean. The industrial atmosphere at Wallsend was drawn through dry air filters and no trouble was experienced. In the high-pressure compressor some carry-over of water from the intercooler occurred and it was found that the dirt then baked on to the compressor blades. This dirt evidently did not stick until wet. A water separator at outlet from the intercooler improved matters. While running, the compressor was washed with water with 1 per cent Lissapol added, and this was effective in keeping the blading clean in the high-pressure compressor.



Inlet temperature of 1,200 deg. F. and exhaust carbon negligible, unless otherwise stated; 84-hour test-line shown on each graph for reference.

a Mothball plus magnesium acetate.
b Mothball plus magnesium sulphate (12 lb. per ton).
c Kerosene plus magnesium sulphate (12 lb. per ton).
d Heavy fuels plus magnesium acetate.
e Mothball plus magnesium carbonate.
f Mothball plus ethyl silicate.

FIG. 7—*Fouling Tests on Gas Turbines of 3500 h.p.*

Corrosion of Heat Exchangers.—The heat exchanger was tubed with aluminum-bronze tubes and serious corrosion occurred even when distillate fuel which contained a normal quantity of sulphur was burnt. The mechanism of corrosion was found to be due to dew-point deposition of sulphuric acid modified by the action of corrosion products which absorbed moisture under idle conditions. A change in materials will obviate this.

Although these details apply to a particular installation, it is believed that the problems mentioned are common to all. A solution for them must be found before the production of high-temperature turbines is undertaken. An investigation follows of the basis of the use of high temperatures in gas turbines up to an inlet temperature of 3000 deg. F.

THEORETICAL INVESTIGATION OF HIGH-TEMPERATURE GAS TURBINE

The first consideration is the limit of gas temperature which a combustion chamber can withstand. In theory, a combustion temperature rise of 4000 deg. F. is possible, but the maximum attainable in practice will depend on the quality of refractory which can be obtained to line the chamber. The limit with present materials would appear to be 3500 deg. F. (1927 deg. C.). Incidentally, carbon has reasonable strength at high temperatures and success in providing an oxidation-resistant coating would greatly increase its temperature range, since carbon has a bend strength of 8000 lb. per square inch at 3090 deg. F. (1700 deg. C.). Zircon is stronger but the low Young's modulus and high conductivity of carbon reduce the thermal stresses set up by thermal transients.

Cooling.—The extreme limit of temperature obtainable without cooling, even with alloys only available on a laboratory scale, is again 1500 deg. F. for long-life gas turbines. Any higher temperature at turbine inlet will in-

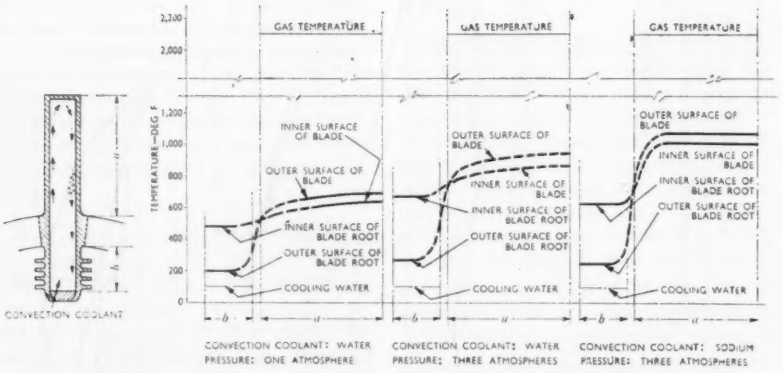


Fig. 8—(left) Convection-Cooled Rotor Blade (Power Jets Patent). (Right) Curves showing estimated change in Temperature of Blade Surface with Various Convection-Cooling Fluids and Constant Gas Temperatures of 2100 deg. F.

volve cooling the metal parts to enable a life of 100,000 hours to be obtained. Among the methods of cooling are:—

(1) Air cooling directly through passages in nozzles and blades, and by shields fitted in the casing and at sides or discs.

(2) Effusion cooling by air flowing through porous sintered material from which blades, nozzles, shield rings, etc., would be formed. (Effusion cooling by water, i.e. sweat cooling, could not in general be considered, as the pores might choke up and the water loss could not be tolerated.)

(3) Water or other liquid cooling directly through the rotor and blades or indirectly by convection cooling in a closed circuit as shown in Fig. 8, which shows a Power Jets patent mentioned in a series of articles in *Engineering*, June, 1953. The work of Pametrada is being done under an Admiralty contract and security considerations prevent Pametrada's own configurations being shown. Convection cooling (which is well known as a principal) applies as shown to rotor blading in which a centrifugal field up to an equivalent value of 30,000 *g* can be generated. Stationary parts of a hot gas turbine would have to be protected by refractory with cooling behind this protection, or effusion-cooled shields and blades could be fitted.

Comparative figures for internal air cooling were worked out for a particular blade profile shown in Fig. 10. This is a reaction blade designed for inlet and outlet angles of flow of 30 deg. and 60 deg. measured relatively to the axial direction. The pitch/chord ratio is 0.7.

The velocity distribution round the blade was found by calculations based on Howell (1941), and Huppert and MacGregor (1949). The heat-transfer calculations were then made separately for the regions of laminar and turbulent flow for the effusion-cooled blade. The same blade profile was used for calculations on air cooling using the following configurations of the cooling passages within the blades:

(1) A hollow blade without insert;

(2) A hollow blade with insert;

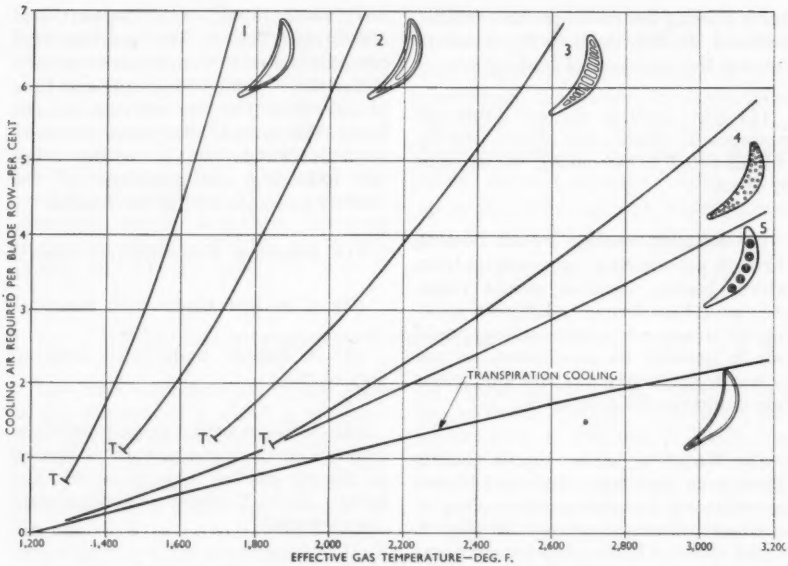
(3) A hollow bade with internal cooling fins;

(4) A blade with a large number of holes of small diameter such as is used in the air-cooled turbine of the National Gas Turbine Establishment (Ainley 1953);

(5) A blade having a smaller number of larger holes with inserts providing secondary cooling surface (Smith and Pearson, 1950).

In regard to these calculations on internal air cooling, it should be noted that the blade temperature increases from blade root to tip, the worst conditions for creep failure occurring in general part of the way up the blade.

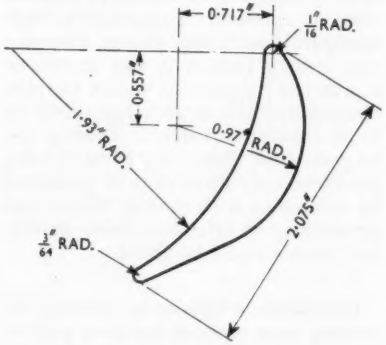
A curve of permissible temperature, drawn to a base of blade height from root to tip, is first produced to give a chosen creep value corresponding to the designed life of the blading at the appropriate stress-value. The actual variation of blade temperature for given values of temperature of cooling air and gas, at a given Reynolds number for the gas and a given ratio between the weight of cooling air and gas, can then be found (Smith, 1948), blade conduction being neglected and constant heat-transfer rates being assumed along the blade.



T, Reynolds number for flow in cooling air passages reached 2500.

Fig. 9—Estimated Weight of Cooling Air per Weight of Gas Required for Different Cooling Arrangements at Various Temperatures

For large cooling air flows this method is sufficiently accurate. For the more efficient designs ((4) and (5), Fig. 9), the variation along the blade of the heat-transfer coefficients is appreciable, and a step-by-step calculation was used in these instances. The results given in Fig. 9 show the progressive reduction in the amount of cooling air required in these five designs and, in fact, clearly indicate the limits of temperature for each type of cooling. Used beyond these limits the cooling air requirements cause a rapid loss in efficiency. It is doubtful whether any great improvement in cooling efficiency can be obtained over that of design (5) for cooling by air flowing radially through the blade. As the effectiveness of the cooling air passages is increased, less cooling air is



Blade profile.

Blade temperature: (2) transpiration cooling, 1200 deg. F.; (2) internal cooling to give the same life as for a blade with a uniform temperature of 1200 deg. F.

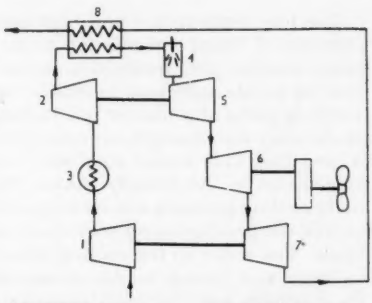
Cooling air inlet temperature, 120 deg. F.; blade aspect ratio, 2.5; pitch/chord ratio 1.7; gas outlet angle, 60 deg., relative to axial direction;

Fig. 10—Blade Profile and Relevant Details for Fig. 9

required and the temperature rise of the air passing along the blade is increased. The increased cooling air temperature towards the tip causes the blade temperature there to approach the maximum permissible value. Any further improvement in effectiveness cannot bring about a further reduction in cooling air quantity since overheating would occur. This appears to be a fundamental limitation on internal air cooling.

Taking the most efficient form of air cooling on the rotor blades (effusion cooling) and using ceramic nozzles and lining of the casing the efficiency and air rate of the cycle shown in Fig. 11 are practically identical with those of the liquid-cooled gas turbine. It is, however, extremely doubtful whether the stainless steel sintered compacts of which the effusion-cooled surface of the blades is formed can be produced with sufficient strength to operate as rotor blades. Therefore, some of the other types already described will be required and the efficiency will always be less than that for liquid cooling. In regard to air cooling—design (3), Fig. 9—a direct comparison has been made between a liquid-cooled turbine and an air-cooled turbine using finned blades in the rotor. The comparison, made at a temperature of 2200 deg. F. at turbine inlet, and a pressure ratio of 15, is shown in Table VII.

In these comparable figures between air and water cooling, the only change has been in the rotor blading. If the turbine had been wholly cooled by air, the figures would have been considerably worsened. Figures given by Ainley (1953) fully substantiate the figures given here, since a peak aerodynamic efficiency of the stage of 79 per cent was obtained. In addition to cooling the rotor blading, cooling of nozzles, casing, rotor body, and other parts will be required. For air cooling thin metal shields spaced off from these more robust parts, which must be protected, are therefore necessary. Such construction tends to be flimsy, although it would be suitable for plant of short or medium life.



1. Low-pressure compressor.
2. High-pressure compressor
3. Intercooler.
4. Combustion chamber.
5. High-pressure turbine.
6. Intermediate-pressure turbine.
7. Low-pressure turbine.
8. Heat exchanger.

Fig. 11—Diagram of High Temperature Gas Turbine Cycle

TABLE VII—COMPARISON BETWEEN A LIQUID-COOLED AND AN AIR-COOLED TURBINE

Type of rotor blade	Thermal efficiency, per cent		Air rate, lb. per s.h.p.-hr.	
	With heat exchange: 0.75 Thermal ratio	Without heat exchange	With heat exchange: 0.75 thermal ratio	Without heat exchange
Air-cooled (design (3), Fig. 9)	37.8	31.1	16.0	15.3
Water-cooled	40.9	32.3	15.3	14.7

The low temperature and high heat capacity of water (in relation to air) make this the ideal medium to remove heat at a rate sufficient to enable the working parts of a marine gas turbine to develop the strength necessary for a long life. This would also lead to a robust design. As already shown, the main cooling passages can be large and should not penetrate any portion of the blade. The water in the cooling circuit in rotor and casing would, of course, be distilled, but the heat exchanger necessary to reject the heat to circulating water drawn from the sea would not be large. In more specially developed types of hot gas turbine the heat removed might generate low pressure steam. As the sealed coolant, for example, water, in the blade proper may even cool the blade too much at high centrifugal speeds, metals such as magnesium or aluminum may be used so that convection cooling of the rotor blades only begins when the blade temperature exceeds the melting point of the metal. New problems arise of intergranular attack of the high temperature alloys of which the blades are formed by, for example, molten aluminum, but again they are not insoluble. The metal temperature at the leading and trailing edges of the blade will be higher than the mean temperature, but even this is to some extent under control through modifications in the shape which are still acceptable according to aerodynamic considerations.

Fig. 8 shows the estimated metal temperatures for a particular design of convection-cooled blade with water or sodium in the sealed chamber inside the blade. The calculations are performed for a gas temperature of 2100 deg. F. at a pressure of 1 atm. in the case of water. The change of temperature of the blade is then shown for water with the gas at a pressure of 3 atm. and a similar condition of gas with sodium as a coolant, the gas temperature being 2100 deg. F. A reduction in cooling loss would be obtained by choosing metals with higher melting points.

CYCLE CALCULATIONS

To obtain estimates of the performance of a high temperature, liquid cooled gas turbine, cycle calculations have been carried out for a practicable design of this type. Cooling losses were calculated in detail using the methods given in Brown (1950a and 1951). It was assumed that the blade temperature could be maintained at 1200 deg. F. in all cooled stages by appropriate design of the cooling system. Fig. 12 shows the cooling loss (as a percentage of the work done) for a turbine stage operating at 1 atm. gas pressure and at various gas temperatures, and Fig. 13 shows how the total cooling loss so determined varies with pressure at the same range of temperature. It will be seen that high pressure is associated with lower cooling loss. Cycle calculations also show that high temperatures require high pressure ratios.

One more consideration has to be taken into account before cycle calculations can begin. As shown in the earlier paper (Brown 1950a) cooling loss is equivalent to a negative reheat factor. A basic turbine efficiency of 83 per cent has been assumed. The variation of turbine efficiency in relation to cooling loss and pressure ratio was calculated. It will be found that at a basic efficiency of 83 per cent the effect of reheat due to losses and of cooling loss cancels out when the cooling loss is 20 per cent. The expansion line is

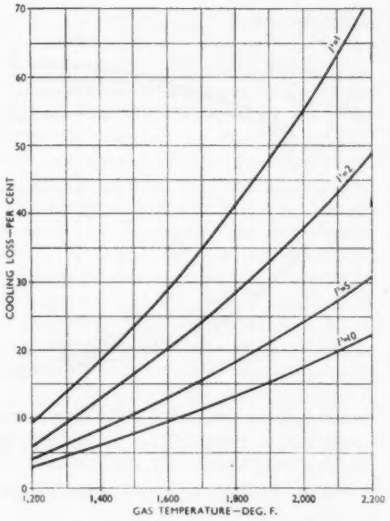
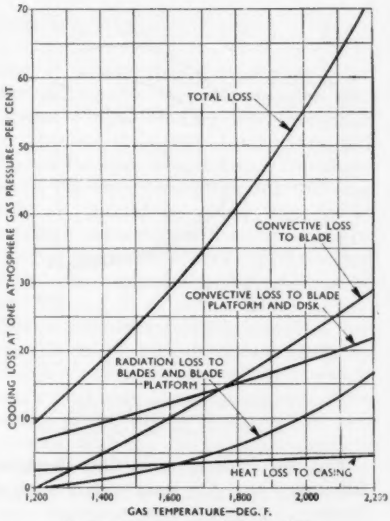


Fig. 12—Estimated Cooling Losses per Stage at 1 Atm. Gas Pressure for Liquid-Cooled Gas Turbine with Ceramic Nozzles and Ceramic-Lined Casing.


COOLING LOSS AT ONE ATMOSPHERE GAS PRESSURE—PER CENT
GAS TEMPERATURE—DEG. F.
TOTAL LOSS
CONVECTIVE LOSS TO BLADE
CONVECTIVE LOSS TO BLADE PLATFORM AND DISK
RADIATION LOSS TO BLADES AND BLADE PLATFORM
HEAT LOSS TO CASING

P, gas pressure at stage in atm.

Fig. 13—Estimated Total Cooling Loss per Stage in Liquid-Cooled Gas Turbine at Various Pressures

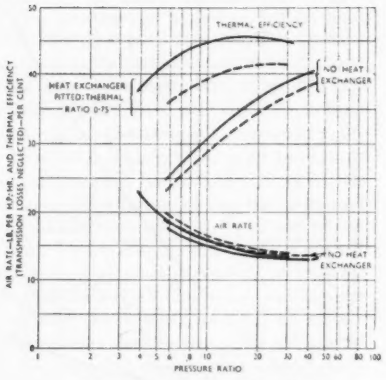
then isentropic. The other assumptions made are given in Table VIII.

TABLE VIII—ASSUMPTIONS MADE IN CYCLE CALCULATIONS

Compressor efficiency assumed, per cent	85
Combustion efficiency, per cent	98
Heat exchanger effectiveness, per cent	(a) Zero (b) 75
Ambient air temperature, degrees Fahrenheit	60
Temperature after intercooler, degrees Fahrenheit	70
Pressure drops:	
Intercooler, per cent	2
Combustion system, per cent	2
Inlet and outlet ducts, total, per cent	1
Heat exchanger if fitted, total, per cent	4½

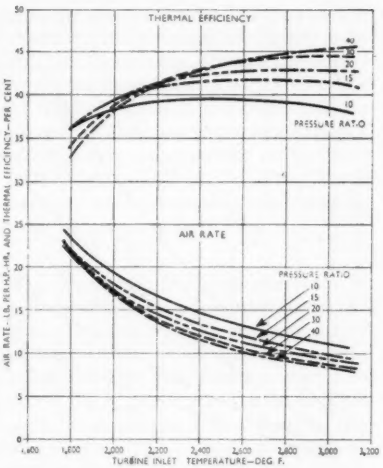
The nominal pressure ratio examined = (pressure at high pressure compressor discharge) / (compressor inlet pressure).

From experience the cycle chosen for examination in this lecture is a three-turbine arrangement as shown in Fig. 11. This cycle was carefully considered in 1946 and submitted to the Admiralty for a scheme to operate at a lower temperature and, therefore, reheat was used between the high-pressure and intermediate-pressure turbines. The high-pressure turbine drives the high-pressure compressor; the intermediate-pressure turbine is the output turbine and the low-pressure turbine drives the low-pressure compressor. One stage of inter-cooling is used. Precooling of the low-pressure inlet air can be added if ambient conditions permit. The combined low-pressure unit (turbine and compressor) could be regarded as a supercharger which can be put out of action during part-load running. The effect with and without a heat exchanger of


THERMAL EFFICIENCY
NO HEAT EXCHANGER
HEAT EXCHANGER FITTED: THERMAL RATIO 0·75
AIR RATE
NO HEAT EXCHANGER
AIR RATE—LB. PER H.P.-HR. AND THERMAL EFFICIENCY (TRANSMISSION LOSSES NEGLECTED)—PER CENT
PRESSURE RATIO

Turbine-inlet temperature, 2,200 deg. F.
———— Cooling losses neglected.
– – – – Cooling losses allowed for.

Fig. 14—Variation of Gas Turbine Efficiency and Air Rate with Pressure Ratio



Thermal ratio of heat exchanger, 0·75; cooling losses allowed for.

Fig. 15—Variation of Gas Turbine Efficiency and Air Rate with Turbine Inlet Temperature at Various Pressure Ratios

a thermal ratio of 75 per cent was also examined. The conditions at full load are not affected by the particular configuration shown in Fig. 11; that is, at full load, the turbines driving compressors could be interchanged without changing the results.

These investigations are best summarized by the use of two sets of curves. Fig. 14 shows the effects of pressure ratio at a constant temperature of 2200 deg. F. with and without cooling losses and with and without a heat exchanger. If no heat exchanger is used the maximum thermal efficiency, allowing for cooling losses, occurs at a pressure ratio of over 100 which would require three compressors in series. Without long component trials the matching problems involved could be shortened only by having three compressor drive turbines and the complexity of the set would be greatly increased. It is clear that, if the aim is maximum thermal efficiency without the need for excessive compression ratios, a heat exchanger is necessary.

Fig. 15 shows the effect of temperature at any pressure ratio in relation to thermal efficiency. On each of these sets of curves the air rate is given which is a measure of the size of the installation and of the ducts and piping in relation to the net power developed. In all these instances it has been assumed that the cooling loss in the gas turbine is not used. It is, of course, possible to recover some of the cooling loss if steam is generated and utilized. The investigation of this was made by Brown (1950a) who showed that combined thermal efficiencies of gas and steam plants reach a peak of 49 per cent thermal efficiency when a regenerative heat exchanger of a thermal ratio of 0.95 is used. Despite further work, the earlier curves and findings in relation to water cooling (Brown 1950a) are entirely consistent with those now given.

SOME PRACTICAL CONSIDERATIONS

Compressors. — The axial-flow type of compressor is the most likely to be used in marine applications as it is small in relation to its throughput when compared with multi-stage centrifugal compressors. Fouling has not been the problem which it was feared it would be. From the air rate figure it can be seen that the size of compressors in relation to net output is greatly reduced (by, say, a factor of 3 or more) at high temperatures. At a pressure ratio of 36 the pressure ratio of each compressor is 6, which is about the practical limit for an axial compressor of high efficiency at this time. No change in compressors other than the use of all the improvements at present available is required.

Intercoolers.—The main problem is the removal of water from the cooled air before it passes to the next compressor.

Combustion Chambers.—At an outlet temperature of 2200 deg. F. the air/fuel ratio would be 40 with an air inlet temperature of 700 deg. F., or 50 at 1000 deg. F. Porous wall cooling could be used in place of refractory lining, since no thermodynamic loss arises so long as the dilution occurs upstream of the turbine and temperature striations in the gas stream are not caused. It should be clear that cycle efficiency depends on the mean temperature of the inlet gas to the turbine, although robustness is dependent on the maximum temperature impinging on a section of the turbine such as nozzles, blading, etc. This is why a great deal of attention is paid to a good temperature distribution at the turbine inlet.

Turbine.—Little can be said about the design of the turbine at this time, although the author can report that a single-stage turbine to operate at 2200 deg. F. is now under construction for the Admiralty. Ceramic nozzles and porous-cooled blading were referred to during the 1953 Conference on Steam Turbine Research and Development (Brown, 1953, Figs. 101, 102 and 103). It should be noted that fewer strategic materials will be required in the hot gas turbine with liquid cooling than in the uncooled turbine operating at 1200 deg. F. In fact, indications are that a stainless ferritic material for the rotors will be entirely satisfactory, thereby obviating the troubles which occur with use of austenitic materials owing to the higher coefficient of expansion and the lower heat conductivity of the latter type of alloy. The high-pressure and intermediate-pressure turbines may have the general construction shown in Fig. 16, since it will be an advantage to have them joined axially, leaving the low-pressure turbine coupled to the low-pressure compressor as a supercharger forming a separate sub-assembly. At the inlet end of the turbine, ceramic or effusion-cooled nozzles will be fitted. Some ceramic lining will be required, with effusion cooling fitted at the high-temperature gland and part of the ducting.

Heat Exchanger. — The heat exchangers so far fitted to industrial and marine gas turbines have been of the tubular type. The thermal ratio has been limited by considerations of size and weight to values usually in the region of 70-80 per cent (except in closed-cycle plants, where smaller tube diameters are permissible and higher thermal ratios are economically possible).

A considerable saving in weight and space could undoubtedly be made by adopting designs having secondary heat transfer surfaces, but to be fully effective the extended surfaces would

have to be formed on both the gas and air sides. Such designs involve more complicated and expensive methods of production than the simple tubular type, and might, moreover, be more difficult to keep clean, so that the danger of corrosion and burning due to deposits on the surfaces might arise.

An alternative arrangement which has received attention recently (London and Kays, 1951) make use of separate gas and air heat exchangers with liquid metal coupling. The separate exchangers would probably be of the cross-flow type with the liquid metal flowing through the tubes in a number of passes so as to approximate to contra-flow. The principal advantage of this scheme is that since the thermal resistance in both heat exchangers is almost entirely on the outside of the tubes a considerable saving in weight and volume can be made by using simple gilled tubes. Compared with a direct gas and air heat exchanger having plain tubes, the liquid metal coupled heat exchangers with gilled tubes show a saving in total weight and space occupied of the order of 50 per cent for the same thermal ratio.

A further advantage of this scheme, important in some applications, is that the arrangement of ducting can often be simplified, the individual gas and air heat exchangers being positioned to best advantage and connected only by the relatively small pipes conveying the liquid metal. It may, however, be some time before shipowners are convinced that pumps and joints for liquid metal meet the marine requirements of reliability.

The regenerative type of heat exchanger also offers the possibility of reduced size and weight as compared with the tubular type. In the regenerative type, heat is transferred from the hot gas to the air via a matrix consisting of a large number of fine elements which is exposed alternately to the hot and cold streams. An additional source of loss thus arises in this instance owing to the loss of high-pressure air to the gas side, due partly to the carry-over of air contained in the matrix voids, and partly to the leakage of air past the seals separating the air and gas compartments. One effect of this leakage loss is to give rise to an optimum thermal ratio. As the thermal ratio is increased the effi-

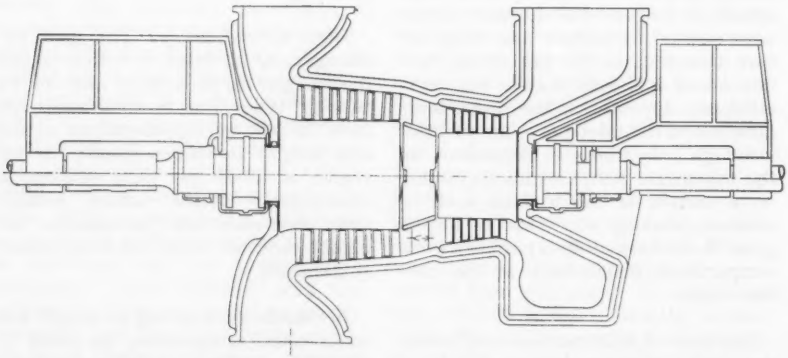


Fig. 16—Possible Configuration of High-Temperature Liquid-Cooled Gas Turbine

TABLE IX—COUNTERFLOW HEAT EXCHANGER SIZES
(Thermal ratio, 75 per cent; ⅜ in. Outside Diameter of Tubes)

	Low-temperature cycle; maximum temperature, 1200 deg. F.; pressure ratio, 6		High-temperature cycle; maximum temperature, 2200 deg. F.; pressure ratio, 20
Heat exchanger pressure loss, per cent	2	4	12
Reduction in thermal efficiency, per cent*	2¼	4½	4¾
Tube length, feet	16	17	27
Number of tubes†	3200	2300	230
Tube plate area, square feet†	7.5	5.4	0.78

*Reduction in thermal efficiency as compared with the same thermal ratio and zero heat exchanger pressure loss. It is expressed as a percentage of the thermal efficiency with no pressure loss.

† Per 1000 s.h.p.

ciency of the gas turbine cycle first increases to a maximum and then decreases again as the leakage loss becomes predominant.

Cox and Stevens (1950) have shown that for a gas turbine cycle with a pressure ratio of 4.35 and a maximum temperature of 1202 deg. F., and with seal leakage at the practicable value of 0.05 lb. per second per foot length of seal, the optimum thermal ratio is 87 per cent, the leakage then being 5 per cent. For a high-temperature, high-pressure ratio cycle, in which the adverse effects of pressure loss and leakage are less, the optimum thermal ratio may be somewhat higher than this.

As regards mechanical reliability of the regenerative type of heat exchanger, Cox and Stevens (1950) have reported much progress. It would appear, however, that thermal distortion can be accommodated more readily in a small exchanger than in a large one.

Fortunately, the ordinary tubular heat exchanger can be used for the high-temperature, high-pressure gas turbine. High-pressure losses can be allowed in the cycle with little loss in efficiency. This fact, coupled with the reduced air rate, leads to a great reduction in heat exchanger size, as is shown in Table IX.

Summary of Deductions on the Hot Gas Turbine.—The best fuel consumption which can be seen within the scope of this survey of hot gas turbines is 0.33 lb. per s.h.p. per hour for all propulsion purposes. This is a possible improvement of 35 per cent over the best fuel rate for steam turbines at the present conditions of 640 lb. per square inch gage, 850 deg. F., as against 24 per cent for the 1500 lb. per square inch gage, 1500 deg. F., with two reheat points. This is a considerably greater improvement than that possible within the present-known limits of a steam cycle. The grounds for a cautious optimism about the use of residual fuel in gas turbines have already been stated. Improvements in bearings, gearing, maneuvering, control gear, etc., very briefly referred to in the section on future steam turbines, would also apply here. Even with the present multi-

stage type of construction which would be required for high thermal efficiency a very great reduction in steaming weight would automatically follow from the figures for air rate. In the main propulsion machinery alone a weight reduction factor of 3 or more could easily be obtained, although the complete machinery installation would not be reduced by this amount since such items as shafting, propellers, ladders and gratings, bilge and ballast pipes, etc., would be relatively unchanged.

CONCLUSION

The effect of T_1, the highest temperature in the cycle, on steam and gas turbines has now been examined as far beyond present practice as possible while still utilizing known materials. The survey shows that, for marine use, steam turbines have still a long way to go before they reach their probable limit. It is also hoped that, throughout the lecture, the close interaction and relation between the steam turbine and the gas turbine, particularly in the high-temperature field, have been demonstrated. It is clear that the high-temperature gas turbine will be a lighter installation possessing higher thermal efficiencies than are possible in steam plant. The fundamental difference, as regards the temperature aspect, between steam cycles (or for that matter the closed-cycle gas turbine) and cycles for open-cycle gas turbines is one of heat transfer through the superheater tubes as against the direct generation of heat in the working fluid. The pipes, nozzles and blades can be cooled in a steam cycle, but there does not seem to be any way of surmounting the problem of transmitting heat of the highest temperature and pressure which the superheater (or the air heater in a closed-cycle gas turbine) can stand. This sets a natural limit to the temperature of the steam cycle, which does not apply with the open-cycle gas turbine. The economics of the changes suggested have not been examined. The way will be hard, but there are no grounds for pessimism. It may be objected that the use of strategic materials required for high-temperature turbines, both steam and gas, will rule them out. It must, however, be remembered that even in a high-temperature installation the portion of the superheaters piping, and the hot part of the high-pressure tubing involved is about 2 per cent of the total weight, "steam up." On the other hand, surely oil (on which nearly all ship propulsion depends) is among the most important of strategic materials.

In the projected use of nuclear power the heat produced by the pile will require conversion to mechanical work by means of either steam or gas turbines, and no essential change in the type of construction other than what is needed for protection against radiation will be involved. Already there are doubts, however, about the availability of uranium in relation to the power generation requirements of the future.

There is no apparent reason to suppose that steam or gas turbines will be superseded as prime movers. These changes in temperature to achieve higher thermal efficiency will become imperative, since, during its effective life, a ship will consume oil representing, say, 25,000 per cent of the machinery weight. It is left to others to decide whether this attempt to survey the field of high-temperature turbine propulsion has been sufficiently convincing. Of the necessity for the survey there can be no doubt.

THE VELOX BOILER OF THE TURBINE SHIP "VILLE DE TUNIS"

ACKNOWLEDGMENT

This article was published in the September 1953 issue of *The Brown Boveri Review*.

Even the earliest designs of Velox boiler plants exhibited the characteristic properties which make them particularly suitable for marine application, namely, high efficiency, fully automatic control, convenient and quick cleaning facilities, adjustability of steam temperature, rapid starting and quick cooling of boiler, completely smokeless combustion, small size, and easy replacement of parts, all of which are advantages of particular importance on shipboard. Only a short time after the first Velox boilers in land installations had been taken into service, two marine plants were built. In 1935 the Compagnie Electro-Mécanique (C.E.M.) fitted the passenger steamer "Athos II," belonging to the Messageries Maritimes, with a Velox boiler for supplying steam to a reducing turbine operating at the—for that time—extremely high steam figures of 58 kg/cm^2 g and 480°C. A few years later the first ship exclusively fitted with Velox boilers, the passenger steamer "Bore II," was built for the Abo-Stockholm line. Unfortunately the war prevented the operating experience with these two vessels from being fully exploited for the further development of marine Velox boilers. The experience gained in about 5,000 operating hours with the "Athos II" and during roughly the same period with the "Bore II" was, however, available at the outbreak of hostilities.

In 1948 the C.E.M. received an order from the Compagnie Générale Transatlantique for three Velox boilers for the "Ville de Tunis," a fast passenger liner of 9,200 gross registered tons. The ship operates on the Marseilles-Algiers, Marseilles-Oran, and Marseilles-Tunis routes and has a normal speed of 20.5 knots. It operates for stretches of 18 to 25 hours with periods of the same length in port. The ship is equipped with three Velox boilers each designed for 30 t/h at 57 kg/cm^2 g and 480°C. at the superheater exit. The feedwater is preheated to 120°C by steam bled from the main turbines and exhaust steam from the auxiliary turbines. The main propelling machinery consists of two geared turbines developing together 15,000 h.p. at the propeller shaft which runs at 150 r.p.m. Two 1000-kVA turbo-generator sets and three 400-kVA diesel-generator sets provide electrical power.

The improvements obtained from experience with land-based installations are incorporated in the new boilers. In addition the experience gained at sea with the abovementioned marine Velox boiler was, of course, taken into account.

The boiler consists of a combustion chamber, a separate superheater, a regulating evaporator connected in parallel with the superheater on the gas side, and the charging set consisting of a gas turbine and compressor which are fitted with plain bearings. A small auxiliary steam turbine is provided for accelerating and regulating the charging set, and also an electric motor for starting it. The foundations and supports of the boilers are designed to prevent any excessive forces or deformation being set up by the rolling and pitching of the ship in heavy seas.

In a land boiler the regulating evaporator serves to maintain constant the live-steam temperatures at partial loads of the boiler. This surface is so computed that the guaranteed live-steam temperature and the required gas temperature at the gas-turbine inlet is obtained with the throttle valve partially open so that the temperature can be varied in either direction. Upon deposits accumulating in the boiler, which usually start on the fire side, the gas temperature at the superheater inlet rises, and if the superheater element is not affected to the same extent the live steam temperature will rise at the same time as the gas temperature at the gas turbine inlet. When this happens the regulating evaporator compensates for the temperature rises.

In comparison with that in a stationary plant the regulating evaporator is considerably larger for marine applications where specifications often also call for a lower steam temperature for astern operation, especially when no high-pressure astern turbine is fitted and it is not desired to subject the casing of the low-pressure turbine to the full temperature of the live steam. When the throttle valve on the regulating evaporator is completely open, the steam temperature of the "Ville de Tunis" boilers can be lowered by about 80°C. In this installation the throttle valve is operated from the turbine control board so that the casing of the low-pressure turbine can be protected against excessive temperatures.

For space and weight considerations a Ward-Leonard set, as used in stationary installations for speeding up the charging set and for utilizing any excess power generated by the gas turbine, was dispensed with here. The charging set of the boiler is equipped with a small auxiliary steam turbine and a starting motor. The lighting and power system of the ship is fed by the diesel-generator sets when the boilers are shut down.

The starting motor of the charging set is a 40-kW induction motor coupled to the set through an overrunning clutch.

The starting procedure for the boilers on shipboard is as follows:

After the feedwater pump has been started and the boilers filled, the circulating, control-oil, and fuel-oil pumps are switched on. No steam is available in the "Ville de Tunis" to preheat the heavy oil when the ship is cold so that the first boiler has to be started on diesel oil. The starting motor accelerates the charging set to about 1,500 r.p.m. and firing of the boiler is initiated by introducing an electric igniter and opening the fuel-oil valve. The main steam valve remains closed at first. The live-steam pipe for the auxiliary turbine branches

off between the superheater outlet and the main steam valve, the valve to the turbine remaining open. As soon as steam is raised it flows through the superheater so that there is no risk of the latter becoming overheated. Subsequently the steam enters the auxiliary steam turbine which takes over the load eight to ten minutes after ignition of the boiler and then speeds up the charging set. When 1,500 r.p.m. is exceeded the starting motor is automatically cut out. The steam pressure continues to rise until, after about 15 to 20 minutes, the full boiler pressure is reached. As soon as steam is available the heavy oil can be preheated and upon this reaching the required temperature the boiler is switched over to heavy oil. When steam is available from the first boiler for the heavy oil heaters, the other boilers can be started direct with heavy oil.

With the described arrangement it is not possible to utilize any excess power of the gas turbine. In order to enable the speed of the charging set to adjust itself to the falling fuel consumption with decreasing load, the gas turbine is fitted with an automatically controlled gas by-pass valve which opens when the nozzle valves of the auxiliary steam turbine are closed completely by the automatic control gear.

The boiler insulation is supplemented by a smooth steel-sheet enclosure which completely surrounds the combustion chamber superheater and regulating evaporator. This casing is not in metallic contact with hot parts and has made the best insulation considerably more effective. The gas turbine is fitted with a similar enclosure.

The suction air for the compressors is taken from bulkheads situated below the compressor inlets, which are fitted with baffles to separate out water and reduce noise. This design has proved very satisfactory, the noise of the axial-flow compressors being completely muffled. Furthermore, in order to facilitate dismantling on shipboard, the gas pasages between the combustion chamber, superheater, and regulating evaporator are fitted with bolted covers, while the cooling coils and walls of the superheater and the regulating evaporator are attached to the circulating pump system by means of screwed connections. A common switch panel is provided for the supervisory and operating instruments of the three boilers.

The 10×15 m space available for the erection of the Velox installation, which was provided to accommodate normal boilers, necessitated careful study to determine the most favorable position for the three boilers, taking into account the already fixed position of the funnel. With the aid of a model the accessibility and disposition of the main pipe connections were examined. To enable the superheater and regulating evaporator elements of the two outside boilers to be dismantled without having to provide an excessively wide hatch in the main deck, it was decided to arrange the outer boilers symmetrically (Fig. 1). The charging sets are located between the hull and the boiler in each case. The component parts of the boilers remain identical so that the number of spare parts which has to be held in reserve is not affected by this arrangement.

In the course of the summer of 1951 the C.E.M. carried out exhaustive tests on the first boiler on the test bed. These showed that the guaranteed efficiency of 90.5% had been reached. The other two boilers were installed without any previous test.

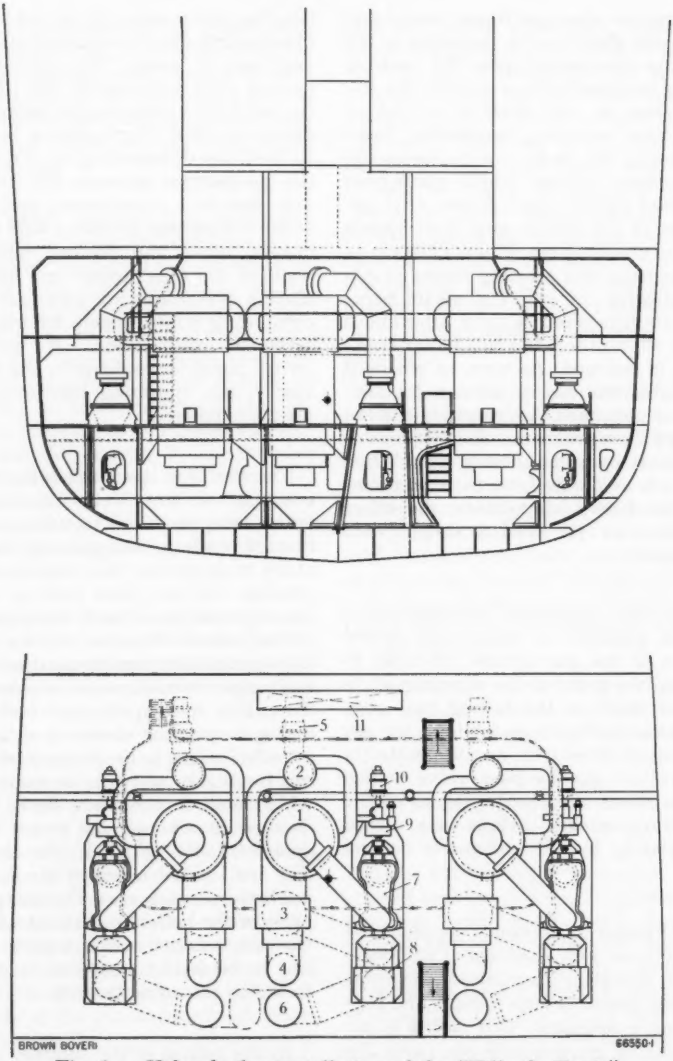


Fig. 1 — Velox boiler installation of the "Ville de Tunis"
Elevation and plan of the boiler room

1 = Combustion chamber with evaporator tubes
2 = Water separator
3 = Superheater
4 = Regulating evaporator
5 = Circulating pump
6 = Economizer
7 = Charging compressor
8 = Gas turbine
9 = Regulating steam turbine
10 = Starting motor
11 = Switchboard

In February 1952 the acceptance tests were carried out at sea with satisfactory results. The fully automatic control operates quite steadily even with two or three boilers connected in parallel to the same steam main, and the men quickly became accustomed to operating the boilers. During the trials the average fuel consumption over 12 hours was measured at a speed of 21.5 knots. The measured consumption of 157 kg of normal-quality heavy fuel oil per mile lay about 15 kg below the guaranteed consumption rate for the ship. To test the speed the "Ville de Tunis" steamed at 23 knots on two boilers, this speed having been fixed as the upper limit for the trial. The foregoing figure was deliberately not exceeded, although this would have been easily possible with these boilers. A series of maneuvers showed that the Velox boilers operated very flexibly. The rapidity of regulation is particularly borne out by an incident which occurred during docking after the trial trip. One of the boilers had already been shut down, while the other was only supplying 8 t/h of steam for the turbogenerators. Following a faulty maneuver by a tug the unexpected command "full speed astern" was received. This command was carried out by the crew and the steam output rose within a few seconds to 27 t/h without any difficulty. The trip from Lorient to Marseilles, where the vessel was handed over to the owners, was carried out at an average speed of 22.04 knots without the overload valves of the turbines being opened. This was only possible by keeping the boiler pressure at around 60 kg/cm^2 g during the whole voyage instead of at the normal 56 kg/cm^2 g.

The "Ville de Tunis" was placed in regular service on March 4, 1952, and since then has run to schedule on every trip. The operating results obtained with this ship by the Compagnie Générale Transatlantique show that a considerable fuel saving has been effected compared with normal boilers.

The inspection which was carried out after the end of the guarantee period in October 1952 testified to the great advances which had been made in Velox boiler design since the building of the "Athos II". The gas passages were clean, with the exception of the economizers in which some soot was found, and this slight deposit could be attributed to the fact that during the summer months the crossings take place in quick succession, the periods in port amounting to only five to six hours. The economizers, which should have been washed out every month (a job lasting at most 2 hours) could thus not be cleaned during the whole summer season. On the occasion of the overhaul the light salt coating on the evaporator pipes was easily removed with metal brushes. This coating is caused by the large proportion of sulphur and also traces of sea water contained in the fuel. The other gas passages were clean even though they had not been washed since the boilers were first fired.

The surface of the blades of the compressors, whose air intake from the boiler room is just above the bilge, were found to be coated with oil due to the oil content of the air. Air filters were subsequently fitted and these are so effective that during the usual half-yearly overhaul of the ship only one of the compressors need now be cleaned. The boilers are now washed out after every 500 operating hours, a job which takes three men six hours and includes the cleaning of all the gas passages. According to the first engineer's report, however, the boilers were initially operated for 1000 hours without washing and no changes in the live-steam or gas temperatures could be noticed. With these long op-

erating times, however, the soot accumulated in the economizer was blown out of the chimney by the first ignition impulse, thus making the deck dirty. It was for this reason that the cleaning period was reduced to 500 hours.

During the period July 2-6, 1953, the second ship equipped with Velox boilers, the "Cambodge", owned by the Messageries Maritimes of Dunkirk, completed its trials with great success. Except for small improvements the boilers are the same as on the "Ville de Tunis". The tests for determining the fuel consumption were carried out over 48 hours at an average speed of 22 knots. The result obtained, around 200 kg per sea mile, lies about 14.5% below the guaranteed specific consumption of 234 kg. The speed trial carried out over a twelve-hour period yielded a speed of 24.52 knots compared with the value of 23.5 knots guaranteed. Inspection of the boiler after the trials showed that the gas passages and the inside of the gas turbine were completely clean thanks to the excellent combustion. The "Cambodge" will operate on the Marseilles-East Asia route.

ARE WE NEGLECTING THE DIRIGIBLE?

J. R. GOODYKOONTZ

THE AUTHOR

is a native of Texas, and a graduate of the U. S. Naval Academy in the class of 1944. During World War II he served in the gunnery department of USS Ranger and USS Quincy, and during the early post-war years was communications officer of USS Mindoro. He resigned from the Navy in 1947. Presently he is with the General Electric Company in Schenectady, New York.

Man was long possessed by the dream of flight. This dream was undoubtedly inspired by the birds which he observed flying about without any apparent difficulty. Unfortunately the birds not only inspired man's dream but provided him with preconceived notions as to how flight might be achieved. He reasoned, quite naturally, that to fly he had merely to construct wing-like mechanisms and to hold or flap these about in the proper manner. To power the contraption he would of course use his arms and legs. So natural is this idea of propelling one's self through the air that it persists even today and hapless dreamers continue to kill themselves by taking off, unaccountably, from high places such as cliff edges and roof tops.

Things took a rather unexpected turn then, when in June of 1783 (after centuries of unsuccessful flapping), two brothers named Montgolfier invented the paper bag full of smoke. This device did not flap or oscillate or whirl or for that matter do much of anything. It simply took off and went up.

The Montgolfier brother's invention immediately attracted a great deal of interest and improvements in the revolutionary device were made rapidly. By August of that year a greatly advanced model, fabricated of silk and rubber and filled with hydrogen, was demonstrated in Paris. The demonstration was well executed. The balloon, rising grandly into the air, actually disappeared into the clouds much to the surprise of the excited spectators.

The spectators who saw the thing come down were even more surprised since they lived in Genoesse, some fifteen miles from the launching site, and had not heard of the scientific experiments. Mistaking the balloon for a monster from outer space, these heroic people attacked it with muskets and

pitchforks and the unfortunate thing was totally destroyed.

This was a very slight setback however and development continued in an orderly fashion. Animals were sent up and in October of 1783 one Jean Francois Pilatre de Rozier went aloft (some 84 feet) in a captive ballon and returned to earth unharmed. In 1785 two men crossed the English channel.

The spherical balloon eventually evolved into the cigar shape and in 1852, over a century ago, Henri Giffard flew the world's first dirigible which was driven by a three horsepower steam engine. In 1898 von Zeppelin formed his famed company for the manufacture of airships.

Meanwhile the Wright brothers were years away from their first flight and it was not until the 1900's that Breguet, Sikorsky and others were seriously attacking the extremely difficult problems of the helicopter.

After such a brilliant head start it is difficult to understand why lighter-than-air craft are not farther along than they are today. Particularly in regard to the helicopter, which is more closely related to the dirigible in function, it is difficult also to see why the dynamic lift achieved by rotating blades is superior to the static lift of a gas filled chamber. Certainly if we kept ships afloat by the same means, that is, by directing streams of water vertically downward, our powers of judgement might well be questioned.

But while the lighter-than-air idea seems basically sound it is true that the dirigible (or blimp) in its present form has less positive control than the helicopter. This lack of control is particularly apparent in the vertical direction and makes landing a dirigible a hazardous operation. On the other hand power failure in a dirigible does not necessarily incite hurried and feverish prayers among the passengers.

Yet to admit the minor ills of the dirigible is not to explain its general failure. Something more than minor ills is needed to push a device to the verge of extinction. Probably the major fault does not lie within the dirigible at all but without: namely, that there has simply been a gross lack of development of the dirigible during its hundred years of existence.

Consider for example the development of the airplane during the last *fifty* years. In the frail, kite-like planes of fifty years ago there was hardly a suggestion of today's Skyray or Cutlass. In the interim there have been planes of every conceivable form. There were planes with three wings, two wings, one wing, planes with propellers pushing, propellers pulling, or both; planes with tails up, tails down, tails in front (actually these planes flew backward), two tails, no tails; planes for the sea, planes for the land, amphibious planes. And on today's drawing boards are convertaplanes which will advance the airplane to even more unusual and interesting configurations. But compare today's blimp to the dirigible Henri Giffard flew around a hundred years ago. Both are essentially the same: a large cigar shaped gas-filled chamber with a gondola fastened on below, engine driven propellers giving the craft a forward motion, flaps in the rear for steering.

While this picture may not actually prove neglect, we certainly cannot claim that it commends our ingenuity.

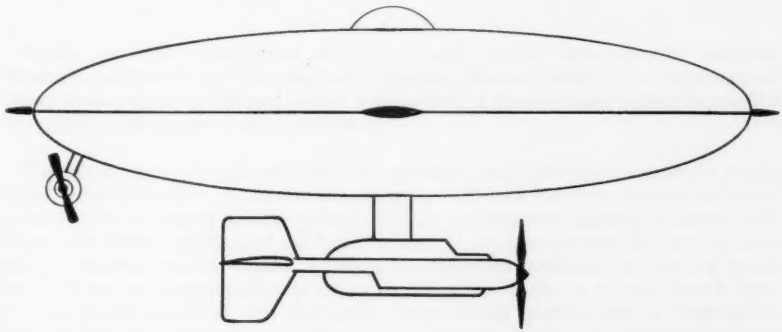
So let us make the simplifying assumption that the dirigible is more neglected than hopeless. And situating ourselves comfortably in our armchair, and comfortable too in the knowledge

that we could hardly make the situation any worse than it is, let us redesign the dirigible from scratch.

We start off with a balloon, roughly spherical in shape, which is filled with helium and gives us lift. Now if we wish to move this thing sideways through the air it is apparent that its shape should be changed to decrease air resistance. The cigar shape has been tried before so instead let us mash it flat so that we have a sort of flat disc. We observe that the new shape is symetrical in the horizontal plane which means that we do not necessarily need to steer or reorient it when we change its direction of motion. Thus the inate clumsiness of turning a large bulky object is avoided.

To power the new dirigible we will use engines and propellers since they are handy. Now we know that to change the direction of motion the direction of thrust must be changed so it occurs to us that the easiest way to do this is to suspend the power plant from the center of the disc (from the underside of course to keep the center of gravity low) and to rotate the power plant relative to the disc when we wish to change our direction of flight. In fact we might as well rotate the whole gondola since it is likely that the pilot will want to see in the direction in which the craft is moving. Thus the craft shown in the figure begins to shape up.

Since we are able to rotate the gondola relative to the disc (by means of motor powered wheels located on the central shaft or by using the rudder) we are also able to rotate the disc relative to the gondola. Perhaps the easiest



way to do this would be to install a second engine and propeller at the periphery of the disc with the thrust directed tangentially. Then if flaps are provided, also along the periphery of the disc, a helicopter action can be achieved providing control in the vertical direction. During such an action the disc would be maintained in a horizontal attitude and the gondola on a constant heading. The flaps and tangential power plant could be controlled electrically from within the gondola via slip rings and would be used only for vertical maneuvering since, during cruising, lift would be provided without cost in power by the helium.

There are many details which would have to be worked out to enable this craft to fly successfully if indeed it

could in fact fly at all. Undoubtedly other ideas better than this one could be originated, tested and applied if an aggressive development program for dirigibles were in existence and if there were a climate of favorable public opinion. But apparently no one, or at least all too few, wants a machine that will hover, fly up, down and sideways, and forward of course, in all kinds of weather, around the world without landing, economically.

This is certainly unfortunate. We may, like the people of Genoesse, take a dim view of the dirigible. But if we do, let us first assure ourselves that our reasons for doing so are better than theirs. After all, they had not even heard of the scientific experiments.

SHIPS, MACHINERY and MOSSBACKS

The Autobiography of a Naval Engineer

By VICE ADMIRAL HAROLD G. BOWEN, U.S.N. Retired

President of the Society in 1938

With a Foreword by

FLEET ADMIRAL WILLIAM D. LEAHY, U. S. Navy

Published by Princeton University Press

384 pages. $6.00

Many elements in the naval and engineering worlds have awaited Admiral Bowen's book with various emotions. Admiral Bowen is known to be a man of direct action who uses direct words without all of the restraint which is usually exercised by those who seek preference.

The book covers a span in time during which engineering advances in many fields were extreme. His naval experiences included the introduction of electronics and its varied applications including particularly radar; of steam turbines and diesel engines, of oil burning and of nuclear energy. In part, he describes his own contributions. Perhaps his greatest contribution applied to all fields. When in a responsible position he did not hesitate to take a chance once he was convinced that the particular engineering gamble had a reasonable chance of success and, if successful, would pay off handsomely. Certainly hindsight marks him as highly successful and to have made notable contributions to engineering and to the Navy, not as an inventor but as an administrator.

The book should be read by every naval officer and by every civilian naval engineer. Those readers who lived in parallel with Admiral Bowen, in whole or in part, will be able to discern that, in general, his facts are accurate. Where opinion enters in, it is doubtful that all of those who have disagreed with Admiral Bowen have been converted to his views. In many cases he has already been proven right. It will take a few more years to make possible a final analysis of the full effectiveness of his career but he can certainly, at this time, be characterized as one of the most valuable naval engineers which the United States has ever had.

DESIGN FOR DECISION

By IRWIN D. J. BROSS

The MacMillan Co., New York

266 pages

"Design For Decision" is a book which might well be read with profit by anyone with a reasonably good education. It is particularly recommended to engineers and administrators.

The author, a consulting statistician, writes with a clear style, with humor which does not obscure the seriousness of his purpose and certainly with knowledge of his subject.

The value of statistical analysis for reaching sound decisions and the need for data are left clearly in the reader's mind. The author uses the analogy of a broad river with two islands. On one bank of the river is the REAL WORLD and on the other the ABSTRACT. Collection of data and its refinement bridges the stream between the real world and the first island. A mathematical model carries the roadway from the abstract to the second island. Statistical Analysis completes the path by constructing a bridge between the two islands.

A review of the chapter titles should clearly describe the book. These are:

1. History of Decision.
2. Nature of Decision.
3. Prediction.
4. Probability.
5. Values.
6. Rules for Action.
7. Operating a Decision-Maker.
8. Sequential Decision.
9. Data.
10. Models.
11. Sampling.
12. Measurement.
13. Statistical Inference.
14. Statistical Techniques.
15. Design for Decision.

FASTER THAN THOUGHT

A Symposium on Digital Computing Machines

Edited by B. V. Bowden, M.A., Ph.D. (Contab.)

Published in London by Sir Isaac Pitman & Sons, Ltd.

The reviewer has not encountered any book written in the United States which presents the subject of the Digital Computing Machine in such a readable and understandable fashion. The book is full of historical anecdotes and of humorous remarks which enhance readability many-fold without detracting from the serious purposes.

The book clearly expresses the British point of view which is probably somewhat more conservative than the one usually encountered in the United States. Naturally most of the space is devoted to a description of machines which are built or building in Great Britain. Reference is made in briefer style to many American machines.

This volume is recommended to the engineer who is seeking a starting education in the Digital Computer. From it, as he desires, he should be able easily to proceed with his education. During this latter phase he can assimilate the American point of view, if and as it differs from the one put forth by Dr. Bowden.

ENGINEERS AS WRITERS

Growth of a Literature

Edited with Introductions and Critical Comments by WALTER J. MILLER

Dept. of English, Polytechnic Institute of Brooklyn

and

LEO E. A. SAIDLA

Head, Dept. of English, Polytechnic Institute of Brooklyn

With a Foreword by H. S. ROGERS

President, Polytechnic Institute, Brooklyn

D. Van Nostrand Co., Inc., New York

Copyright 1953

The reviewer found this book to be quite intriguing. Of the sixteen chapters, the first is introductory and each of the others is an example of the writings of an engineer. The coverage is from Marcus Vitrulva Pollio (278 B.C.) and Sextus Julius Frontinus (97 A.D.) to Herbert C. Hoover and Arthur E. Raymond.

Although the book is intended as a textbook for teaching writing to engineering students, the author's selections are so intrinsically readable and interesting that it is easy to overlook the basic purpose. With the aid of discussion and questions the authors lead the student to an analysis of the classical writing and to discovery of literary flaws.

Either as a book for interesting reading or as a textbook, it is highly recommended.

EXTRACTS FROM ENGINEERING, APRIL 9, 1954

AN ENGINEERING TECHNIQUE APPLIED TO ECONOMICS

The Mechanism of Economic Systems. An Approach to the Problem of Economic Stabilization from the Point of View of Control-System Engineering. By Professor Arnold Tustin. William Heinemann, Limited, 99 Great Russell-street, London, W.C.1. (25s. net.)

Professor Tustin, Head of the Department of Electrical Engineering at the University of Birmingham, holds this year the first Webster Professorship at the Massachusetts Institute of Technology. To inaugurate this well-merited distinction he delivered, on February 11 last, in Morse Hall of Walker Memorial, at Cambridge, Massachusetts, a public lecture on "Electrical Engineering in a New Kind of University." This choice of subject was completely appropriate both to the occasion and to the speaker. Professor Tutin, like the late Edwin S. Webster who endowed the chair of electrical engineering at M.I.T., has a special concern for the social and economic consequences of new scientific knowledge and ideas. He believes that the education of engineers must be designed for their full development as mature human beings, and that M.I.T., with its unique status in education, may become the prototype of a new kind of "university for the modern man," built around the teaching of applied science as its core.

Of the many and varied implications of this broad concept of a change from traditional classics to modern science as a basis for cultural education, two at least are outstanding. One is, that the aim and purpose of all knowledge, including science and its applications, should be the betterment of human welfare. The other, complementary to the first, is that specific problems of human welfare in fields such as medicine, nutrition or economics, as well as in the more obvious territories of man's control over natural resources to increase his comfort and convenience, are challenge to technologists in many different disciplines and inspiring subjects for purposeful future research. Lest it be thought that such views, however superficially laudable, are basically materialist, it is well to emphasize that Professor Tustin does not accept the too commonly drawn distinction between the domains of science and spirit. He regards as essential tasks for a technological university, first, to recognize that intellect is at best a tool which should be subordinated to good motives; then to clarify what is meant by "good"; and always to sustain an ever-rising standard of ethical values.

Against this background of the philosophy of a remarkable electrical engineer, Professor Tustin's recently published book on the mechanism of economic systems can be viewed more sympathetically than might seem possible, to engi-

neers if not perhaps to economists, at a first consideration of the subject and its necessarily somewhat severe method of treatment. For most engineers nowadays are hard enough put to it to keep abreast of their own technology without attempting to master the intracacies of another which, while admitting its importance, they may well feel is founded on such uncertain and uncontrollable factors as to be inevitably remote from their precise ways of thinking and working. They may be gratified, none the less, that the theory and practice that have proved so successful in the realization of engineering control systems, now appear to offer a new means of attack upon problems that economists have been able to propound but, hitherto, unable to solve.

It has been recognized for many years that close analogies exist between economic problems of the complex interactions among quantities such as income, capital, savings and investment, and automatic control systems in engineering where the corresponding interactions are among physical quantities affecting, say, the navigation of an aeroplane or the processing of chemicals. Many notable economists, J. M. Keynes among them, have found it useful to state such schemes of interdependence in the form of diagrams plainly similar to those used in control engineering theory. Closer examination of the nature of the interdependence between the related quantities serves to strengthen the analogy between the economic and the physical or engineering system, and hence to suggest that the methods of control analysis and the principles used successfully to achieve stability by means of engineering apparatus will prove at the least enlightening, and at best equally successful, in the economic sphere.

To explore this suggestion, to examine its varied aspects, to appreciate its difficulties and limitations, and to give practical expression to its possibilities, are tasks which Professor Tustin, who is an acknowledged authority on control theory, has undertaken with conspicuous success. Starting with a review of some of the simpler economic cause and effect systems, he shows what features predispose them to be inherently unstable, leading to cycles of booms and slumps; and how and where, in principle, stablishing measures may be introduced. Consideration of the irregular disturbances to which economic regimes are subject, and of the factors, additional to those studied in the elementary systems, which must be taken into account before quantitative explanations can become quantitative solutions (or qualitative ideas about stabilization become deliberate, quantitative regulation) entails economic diagrams, or models, of increasing complexity. Professor Tustin's grasp of the way in which a great number of factors interact to influence a vast industrial economy excites an admiration that is surpassed only by the sense of competence with which he analyses the behavior of such a system and indicates how it can be kept under control.

Many of the factors which influence economic stability—international politics, weather and harvests, technical development and invention, to mention a few of the most obvious—are clearly so indeterminate that the utmost the economist can hope, or be expected to do about them is to estimate their differing future effects on the basis of intelligent assumptions. Similarly, and with only slightly less uncertainty, he has to make hypotheses regarding the time lags between causative economic factors and their various consequences. Unavoidable time lags or deliberate delay actions are common enough in engineering control theory, and the methods presented by Professor Tustin for analyzing their effects in economics are among the most directly valuable features of his book. He

fully realizes, on the other hand, that the very long-term problem based on uncertain data, may call for dubious extrapolation, or demand the solution of a large number of generally similar systems differing with respect to assumed values of influential factors considered singly and in combination. The mathematical labor thereby involved might well take so long that economic depression would actually come about before the anticipatory measures that might have prevented it could be discovered and put into effect.

Here, evidently, exists an enormous potential field for the use of electrical computers, which Profesor Tustin very rightly emphasizes. He gives a brief account of representative types of analogue computers and simulators that have come into use in engineering for the study of complex systems, especially such as involve nonlinear relations. From this descriptive matter he proceeds to outline the main requirements of an analogue computer for economic prediction, noting that it would need to embody means for temporarily arresting the passage of "time" in order that changes representing, for instance, hypothetical economic disturbances or policy variations, may be injected at any desired stage.

A principal use for such an analogue, and for the control system methods of analysis which Professor Tustin has established, would be to investigate a reliable presentation of any contemporary state of a national economy, and thence to formulate guiding rules of government action intended to introduce automatic stability. From this standpoint alone, Professor Tustin's book justifies most careful attention by economists, to whom it may introduce new concepts no less than new and powerful technical tools. For engineers and electronic control technologists it will prove a rewarding study, not least by pointing to ways in which their special knowledge can be increasingly useful within the economic system in which they are important shareholders.

EXTRACT FROM THE ENGINEER

26 March 1954

WORKSHOP COSTS AND COSTING

By P. S. HOUGHTON, London

Chapman and Hall, Ltd., 37 Essex Street

A large number of books have been written on the important subject of costs and costing, written by cost accountants, who all too often seemed to imply that their particular responsibility was the main function in an organization. It is all to the good, therefore, to have a work written by an engineer who realizes the necessity of good cost accounting, but at the same time appreciates that its purpose is "to assist the management to control the many aspects of the particular concern," indeed it should be its painstaking handmaid. The author points out that there is often a marked difference between what a manager wants to know and what he should know, but when a good system is installed he will find the two coming into agreement. We are told that even after its inauguration a number of unintelligent questions will be asked; we suggest that a round table conference of all concerned down to the lowest clerk, and a free discussion beforehand will tend to reduce the number of such questions to a minimum.

In the sixteen chapters we are shown how price variation may be accounted for and how a good costing department should help; then we come to the differentiation between direct and indirect expenses, and all the items that are met with in costing, and the personnel concerned, followed by the proper allocation of oncosts, while two chapters are devoted to the way in which a costing system may be created for a new business, and a further two to foundry costing, a very important matter. The value of the application of codes is stressed, and the way in which graphs may assist is indicated. Contract as well as similar costing, and process costing, are satisfactorily handled. Certain extraneous subjects are introduced, such as the different methods of payment, including daywork, piecework, premium bonus schemes, and profit sharing, all part of management rather than costing. The heading of a chapter, "Financial and Cost Accounts Reciliation," comes as rather shock, for we are strongly of the opinion that the two accounts should not be at variance, there being no need for reconciliation. The two should be interlocked. The author carefully explains the different methods employed for recovering oncosts, but does not show any marked preference. We feel he might have suggested that the machine-hour rate method, if applied judiciously, should give the best results in a large engineering works. The book concludes with a number of useful questions based on the subject matter found in the different chapters.

We agree with Mr. Houghton when he asserts that a firm which claims that there is no need for a cost office is the very concern that requires a thorough overhaul, and we feel that the manager of such an undertaking would be well advised carefully to study this book, after which he will probably radically alter his views. It is open to question whether the author is justified in averring that a large number of managers either profess inability to collect data or have a great dislike to doing so. Certainly it is not the case in most large firms, and the two major wars rendered a system of costing imperative.

It would be but a poor compliment to the writer of a book covering so wide a range to find that there was little to criticize or to inspire suggestions, and any that we make are mostly in the way of drawing attention to the desirability of further information on some of the matters described. We should certainly like to know where Mr. Houghton would place his cost accountant in the staff layout. Would he have him report to the chief accountant or to the works manager? While he evidently appreciates the value of a good estimating department and indicates that it should be in close liaison with the cost office, we hope he has not in mind that the estimator should be in a subordinate position, for they should be "opposite numbers," each a valuable check on the other; indeed, we would go further and suggest that regular tabular statements should be made and passed periodically to the general manager, showing, side by side, estimated and actual expenditure. The author would probably agree that often managers after a little while become enthusiastic about the value of cost accounts and ask for more and more detail, resulting in building up too cumbersome a system, but we should like to know how this can be obviated without destroying the welcome enthusiasm. Again, it is most important that the cost of a job should be known as soon as possible after its completion. What does the author consider a reasonable time factor? It is too much like "flogging a dead horse" for a manager to have to investigate a case of apparent excessive cost of an article weeks and weeks after it has left the factory. We miss a comprehensive bibliography, the author only referring to some of his earlier works on management and organization.

Workshop Costs and Costing can be recommended alike to the student who has a leaning towards management and to the manager who begins to realize the necessity for a reliable costing system, one that might even show that by closing one of his branches the profits might increase. It might well be studied by the cost accountant to show him the way an engineer approaches the problem. The book is easy to read, is set out in a methodical way, and is illustrated with useful diagrams, charts and forms.

THE BRITISH SUBMARINE

By COMMANDER F. W. LIPSCOMB, O.B.E., R.N.

Publication Date 6/22/54

Published by Adam and Charles Black, London

Distributed in the United States by The MacMillan Co.

60 Fifth Ave., New York

260 pages. $5.00

The mystery to this book is how the author managed to cram so much into such a few pages. He tells the story of the British Submarine in a very complete fashion from the beginning in 1900 through the Second World War.

As an introduction for the non-naval reader (and perhaps for some of those) Commander Lipscomb starts with four chapters:

I. How a Sumbarine Works.

II. Some Questions Answered.

III. i. Submarine Shore Bases and Depot Ships.
ii. The Building of Submarines.

IV. Accident, Escape and Salvage.

Then five chapters are devoted to the history of the British submarine including both world wars. He concludes with a chapter entitled "Submarines of the Future."

With so much to say and so little space to say it in perhaps an American reader might criticize the author's choice of details to include. Whether he does or does not the average reader should enjoy this book.

FORM IN ENGINEERING DESIGN

By J. BERESFORD EVANS

Publication date May 6, 1954

Oxford University Press, 114 Fifth Avenue, New York 11, N. Y.

94 pages. $1.70

This little book carries a surprising interest to the engineer who has no difficulty in appreciating the importance of "Form" but had previously given it little thought.

The aesthetics of engineering design is a matter of great importance to designers of household appliances where sales appeal is not wholly defined by technical competence. One wonders if sufficient importance has been attached to them in industrial and military design.

WIND TUNNEL TESTING

By ALLEN POPE, M.S.

Supervisor Experimental Anodynamics Division

Sandia Corporation

Second Edition

Published by John Wiley & Sons, Inc., New York

500 pages. $8.50

Publication Date June 21, 1954

The purposes of this book, in the words of the author, are:

To help students taking wind-tunnel laboratory courses.

To furnish a textbook for tunnel engineers, and

To aid beginners in the field of wind-tunnel design.

The second edition has been brought out as a necessity to recognize and include all of the new techniques and new knowledge since the first edition. The result is an expansion in size of about 30 per cent.

The book is beautifully and clearly illustrated and is arranged so that various levels of education are recognized. For example: the treatment of transonic and supersonic testing is restricted to the last two chapters. Thus the first ten chapters can be considered suitable for the customary undergraduate level.

As to the accomplishment of the intended purpose, there seems no doubt.

ENGINEERING ANALYSIS

An Introduction to Professional Method

By D. W. VER PLANCK
Head, Department of Mechanical Engineering
Carnegie Institute of Technology

and

B. R. TEARE, JR.
Dean, College of Engineering and Science
Carnegie Institute of Technology

Publication Date, May 19, 1954

Published by John Wiley & Sons, Inc. 440 Fourth Avenue, New York

338 pages. $6.00

This is a textbook developed in twenty years of teaching experience. It follows the methods employed where students are required to accept and treat problems just as they would come to them as practicing engineers.

The method considers the five stages of engineering treatment:

(1) Defining the specific problem.
(2) Planning the attack including decision as to the principle on which to base the attack.
(3) Executing the plan to a decision or result.
(4) Checking.
(5) Taking stock—learning and generalizing.

The first two of these are "in essence the translation of the engineering situation into mathematical language." The third phase is the purely mathematical one and the last two are "what is done after the mathematical crank has been turned and a result obtained." The book stresses phases 1, 2, 4, and 5. The authors consider that their method of forcing a student to do his own thinking through phases 1 and 2 is markedly superior to a conventional method where the formulation of the mathematics is presented to the student for solution. This certainly is sound for students who expect to go out into a real world entitled to be called engineers.

The book goes through many examples in painstaking detail and includes 122 unworked problems for the student's practice.

CHANGES IN MEMBERSHIP

The Society announces with much pleasure that the following have joined the Society since the publication of the May, 1954, issue of the JOURNAL:

NAVAL

Cigliano, Irving Luigi. Lieutenant, J.G., USNR,
Chief Engineer, Cities Service Oil Co.,
70 Pine St., New York, N. Y.
Mail: Silverside Avenue, Little Silver, N. J.

Crow, Thomas Seabury, Lieutenant, USNR,
Sales Engineer, Marine Sales, General Electric Co.,
Fitchburg, Mass.

Davis, Cabell Seal, Jr., Lieutenant, USN,
USS ROBERT S. WILLSON (DDE 847),
% Fleet P.O., New York, N.Y.

Eastman, Frederick G., Captain, USCG,
447 Commercial St., Boston, Mass.

Hooper, Posey A., Commander, USN,
San Francisco Naval Shipyard,
San Francisco, Calif.

Leavy, Paul Matthew, Lieutenant, USN,
54 Whitman Ave., Syosset, L.I., N.Y.

Lee, Thomas Erling, Ensign, USN,
3520 Vincennes Place, New Orleans, La.

Rascher, George John, Lieutenant, USN,
USS DOUGLAS H. FOX (DD 779),
% Fleet P.O., New York, N.Y.

Rockwell, James, 1st Lieutenant, USMC, Ret.,
Aeronautics & Ordinance Systems Div.,
General Electric Co., 1 River Road,
Schenectady 5, N.Y.

CIVIL

Dutton, Edward Frank H., District Manager,
Le Roi Co. Cochrane Corp.,
916 Ring Bldg., 1200 18th St., N.W., Washington, D.C.

Engles, Peter Joseph, Production Engineer,
J. K. Keeney & Co., Inc., Chicago, Ill.
Mail: 7355 South Shore Drive, Chicago 49, Ill.

Gill, George James, Engineering Rep. Specialty,
Engrg. Div., Room 527 Investment Bldg., Washington, D.C.

Kuehne, Richard, Sales Engr., Marine Equipment,
Lovel Dressel Co., Arlington, N.J.

Littman, Morris Michael, Marine Engineer,
Code 543, Bureau of Ships, Navy Dept.
Mail: 3107 13th Road, So., Arlington, Va.

Ortman, Edward F., Vice Pres.-Gen. Mgr.,
American Welding Co., Inc., 708 S. Caroline St., Baltimore 31, Md.

Safford, Walter Welsch, Manager, Product Planning and Research,
Naval Ordnance Dept., General Electric Co., 100 Plastics Ave.,
Pittsfield, Mass.

Shaneberger, William Earl, Asst. Chief Engr.,
Ingersoll Products Div., Borg Warner Corp.
Mail: 1210 Royce Ave., Kalamazoo, Mich.

Sorenson, Lloyd Raymond, Production Manager,
Newport News Shipbuilding & Dry Dock Co., Newport News, Va.

Symon, Maxwell Staney, Engineering Representative,
Electrical Regulator Corp., Norwalk, Conn.
Mail: 180 East 163d St., New York 51, N.Y.

Wyman, Maynard R., Manager, Engineering & Service,
Apparatus Div., Westinghouse Electric Corp.,
East Pittsburgh, Pa.

ASSOCIATE

Albert, Carlos Jesus, Captain, Philippine Navy,
Naval Attache, Philippine Embassy, Washington, D.C.

Johnson, Reeves Kemp, Jr., Manager, Jet Sales,
Special Products Div., I.T.E. Circuit Breaker Co.,
601 E. Erie Ave., Philadelphia 34, Pa.

Keeney, Cecil Madison, Marine Engineer,
Code 554, Bureau of Ships, Navy Dept., Washington 25, D.C.

King, Samuel M., Manager Radar Sales, Special Products Div.,
I.T.E. Circuit Breaker Co., 601 E. Erie Ave., Philadelphia 34, Pa.

Liu, Tieh Shin, Commander, Chinese Navy,
Chief Engineer RCS HAN YAN (ex DD 429)
Mail: 4 Ho Chun Villa, Tso-ying, Formosa.

Lueckert, Jack A., Application Engineer,
I.T.E. Circuit Breaker Co., 917 15th St., Washington 5, D.C.

REJOINED

Schirmer, Joseph E., Chf. Mach. USN, Naval Member.

DIED

The Society has received with the utmost regret notice of the following deaths of members since the publication of the May, 1954, Journal:

COMAN, V. K., Naval Member

HUSE, JOHN O., Naval Member

SZCZEPOWSKI, Victor C., Naval Member

ASSOCIATION NOTES

ORIGINAL ARTICLES

The editor of the JOURNAL is most anxious to obtain manuscripts of original articles on subjects of interest to naval engineers. Any manuscript accepted for publication becomes the property of the Society which copyrights it upon publication. Authors are paid from $40.00 to $150.00 depending upon length, interest and professional value.

The rules for manuscripts are as simple as we can make them.

1. They must be legible (typewritten, double-spaced preferred) since no proof is submitted to authors for correction prior to printing.

2. Single copy only is required.

3. Mathematical formulae used must be set up, preferably by hand printing, so that there can be no question as to symbols, subscripts and exponents.

4. Any drawing submitted must be black on white. A cloth or paper tracing is acceptable but not required.

5. Photographs may be negatives, but glossy prints are acceptable.

6. Include on a separate page a short biographical sketch(es) of the author(s). 50 to 100 words for each author is desired.

Manuscripts should be addressed to:

Secretary-Treasurer
American Society of Naval Engineers
605 F St., N. W.
Washington 4, D. C.

Manuscripts accepted will not be returned unless specifically requested by the author. If returned, they will be in the condition which has resulted from the work of the printer and the engraver. Immediately following publication, the author is furnished 10 reprint copies of his article free of charge. Additional copies may be purchased from the Society if the request is received 30 days prior to the publication date which is the 25th of the issue month. Estimate of cost of additional reprints, which will vary with the nature of the article and the number of copies ordered, will be furnished on request as soon as possible after the article is set up.

Manuscripts not accepted will be returned, postpaid, by the Society.

Manuscripts which are accepted will be published in the earliest JOURNAL which has not yet been closed (60 days before publication) and for which sufficient material is not already on hand.

PHOTOGRAPHS

Photographs of current or historical interest to readers of the JOURNAL are desired. Any which are accepted by the Society will be purchased by the Society at a standard price of $5.00 each. Such purchase *will not* include any copyright by the Society, but the contributor must hold the Society free from any charge of violation of any previous copyright.

NOTICE OF DEATHS

The Society has no satisfactory machinery for obtaining notice of deaths of members. It is particularly desired that we receive such notice upon the death of any past officer, past member of the Council or member of more than twenty years' standing with photographs and short obituaries. It will be appreciated greatly if any member who learns of the death of a member will advise the Secretary-Treasurer.

SOCIETY LAPEL BUTTONS

Shown below is an illustration of the lapel button of the Society. It is believed that it will be conceded that this is a very fine dignified insignia. It is one-half inch in diameter.

The oak leaves and lettering are red on a gold background.

It is available to all members at fifty cents (50c) each.

Permission is granted to reprint any original article contained herein if the following conditions are met:

a) Credit is given to the JOURNAL with reference to the issue.

b) Credit is given to the author.

c) If the author is a military officer or a civilian employe of the Department of Defense, the following note shall be carried:

"The views expressed herein are the personal ones of the author and are not necessarily the official views of the Department of Defense or of a Military Department."

THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

FINANCIAL STATEMENTS, 1953

TRIAL BALANCE

Cash		$ 5,024.74	
Accounts Receivable:			
Advertisements	$ 2,869.45		
Dues	1,279.50		
Sales	217.31		
Subscriptions	565.00	4,931.26	
Investments:			
U. S. Defense Bonds, Series G	$ 58,000.00		
Washington Gas Light Co. Bonds	997.50	58,997.50	
Furniture		266.36	
Income (Publication):			
Advertisements	$ 7,125.00		
Dues	22,535.14		
Sales	318.47		
Subscriptions	16,051.00		$ 46,029.61
Expenditures (Publication):			
Printing	$ 28,733.09		
Engraving	1,710.32		
Manuscript	3,160.00		
Postage	602.41		
Commissions	176.65		
Exchange	.22	34,382.69	
Interest on Investments			1,500.00
Banquet 1953			2,041.41
General Expense		3,029.89	
Salaries		8,700.00	
Current Profit and Loss		1,506.87	
Banquet 1954		54.86	
Dues Paid in advance			270.98
Subscriptions Paid in advance			7,109.00
Advertisements Paid in advance			112.50
Manuscript Paid in advance		1,060.00	
Capital Account			60,940.67
Petty Cash		50.00	
		$118,004.17	$118,004.17

STATEMENT OF INCOME AND EXPENDITURE

Income

Publication:		
Dues	$ 22,535.14	
Advertisements	7,125.00	
Sales	318.47	
Subscriptions	16,051.00	$ 46,029.61
Interest on Investments		1,500.00
Banquet 1953		2,041.41
		$ 49,571.02

Expenditures

Publication:		
Printing	$ 28,733.09	
Engraving	1,710.32	
Manuscript	3,160.00	
Postage	602.41	
Commission	176.65	
Exchange	.22	
	$ 34,382.69	
Salaries	8,700.00	
General Expense	3,029.89	
Current Profit and Loss	1,506.87	
Banquet 1954	54.86	47,674.31
NET GAIN		$ 1,896.71

BALANCE STATEMENT

Assets December 31, 1953:

Cash		$ 5,024.74	
Petty Cash		$ 50.00	
Accounts Receivable:			
Advertisements	$ 2,869.45		
Dues	1,279.50		
Sales	217.31		
Subscriptions	565.00	4,931.26	
Investments:			
U. S. Defense Bonds, Series G	$ 58,000.00		
Washington Gas Light Co. Bonds	997.50	58,997.50	
Furniture		266.36	
Manuscript Paid in Advance		1,060.00	$ 70,329.86
Liabilities (Accounting Only):			
Dues Paid in Advance	$ 270.98		
Subscriptions Paid in Advance	7,109.00		
Advertisements Paid in Advance	112.50		7,492.48
Net Assets December 31, 1953			$ 62,837.38
Total Assets January 1, 1953			60,940.67
NET GAIN			$ 1,896.71

Respectfully submitted,

/s/ J. E. HAMILTON,
Secretary-Treasurer

Audited and Found Correct:

/s/ CHARLES G. COOPER
/s/ M. DOUGLAS GIBSON, JR.
/s/ JOHN F. HANLON
Audit Committee

SECRETARIES OF THE SOCIETY

Current:

Captain J. E. HAMILTON, U. S. Navy, Retired

Past Secretaries:

1889 P. A. Engineer R. S. GRIFFIN, U. S. Navy
1890 Assistant Engineer W. M. MCFARLAND, U. S. Navy
1891 Assistant Engineer EMIL THEISS, U. S. Navy
1892-93 P. A. Engineer W. M. MCFARLAND, U. S. Navy
1894-95 P. A. Engineer R. S. GRIFFIN, U. S. Navy
1896-97 P. A. Engineer F. C. BIEG, U. S. Navy
1898 P. A. Engineer W. M. MCFARLAND, U. S. Navy
1899 Chief Engineer A. B. WILLITS, U. S. Navy
1900 Lt. Comdr. A. B. WILLITS, U. S. Navy
1901 Lieutenant B. C. BRYAN, U. S. Navy
1902 Lieutenant C. W. DYSON, U. S. Navy
1903 Lt. Comdr. JOHN R. EDWARDS, U. S. Navy
1904 Lieutenant M. E. REED, U. S. Navy
1905 Lieutenant W. W. WHITE, U. S. Navy
1906 Lieutenant C. K. MALLORY, U. S. Navy
1907-08 Lt. Comdr. T. C. FENTON, U. S. Navy
1909-10 Lieutenant H. C. DINGER, U. S. Navy
1911 Commander U. T. HOLMES, U. S. Navy
1912 { Lieutenant JOHN HALLIGAN, U. S. Navy / Lt. Comdr. E. L. BENNETT, U. S. Navy
1913 Lieutenant O. L. COX, U. S. Navy
1914 Lt. Comdr. H. C. DINGER, U. S. Navy
1915-16 Lieutenant A. T. CHURCH, U. S. Navy
1917 { Lt. Comdr. J. O. RICHARDSON, U. S. Navy / Lt. Comdr. F. W. STERLING, U. S. Navy, Retired
1918 Lt. Comdr. F. W. STERLING, U. S. Navy, Retired
1919 { Lt. Comdr. F. W. STERLING, U. S. Navy, Retired / Commander J. S. EVANS, U. S. Navy
1920 Commander J. S. EVANS, U. S. Navy
1921 { Commander J. S. EVANS, U. S. Navy / Commander S. M. ROBINSON, U. S. Navy
1922-23 Commander S. M. ROBINSON, U. S. Navy
1924-25 Commander BRYSON BRUCE, U. S. Navy
1926 Commander A. M. CHARLTON, U. S. Navy
1927 Commander H. B. HIRD, U. S. Navy
1928 { Commander H. B. HIRD, U. S. Navy / Captain O. L. COX, U. S. Navy
1929-30 Commander H. T. SMITH, U. S. Navy
1931 Captain O. L. COX, U. S. Navy
1932 Commander H. F. D. DAVIS, U. S. Navy
1933-34 Commander H. B. HIRD, U. S. Navy
1935 Commander C. S. GILLETTE, U. S. Navy
1936 { Commander C. S. GILLETTE, U. S. Navy / Commander ROGER W. PAINE, U. S. Navy
1937 Commander ROGER W. PAINE, U. S. Navy
1938 { Commander ROGER W. PAINE, U. S. Navy / Lt. Comdr. GUY CHADWICK, U. S. Navy
1939-40 Lt. Comdr. GUY CHADWICK, U. S. Navy
1940-44 Captain J. E. HAMILTON, U. S. Navy
1945 Commander R. T. SUTHERLAND, JR., U. S. Navy
1945-48 Captain F. W. WALTON, U. S. Navy